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POWER LAWN MOWERS: Evaluation of Anthropometric Foot Probes

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U.S. DEPARTMENT OF COMMERCE, Juanita M. Kreps, *Secretary*

Dr. Sidney Harman, *Under Secretary*

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Table of Contents

List of Tables

List of Figures

List of Figures (Continued)

Acknowledgements

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ABSTRACT

This document is the final report for the Consumer Product Safety Commission of an evaluation of the adequacy of existing generic foot probes. The Human Factors Section at NBS compared the dynamic characteristics of three generic probes with those of potential lawn mower users' feet.

Horizontal and vertical insertion distances for the generic probes and the foot data were used to develop safety envelopes for various simulated housing heights. Inspection of the safety envelopes at 6, 8, and 10 cm housing heights indicates that, of the three generic probes, the UK probe most closely approximates the foot data, since only the UK probe passes through the area above the horizontal plane formed by the bottom edge of the housing.

However, a comparison of each individual's data (rather than aggregate data) was made with each generic probe to determine the percentage of participants who would be completely protected by each generic probe. These data indicate that at least one point of each individual's foot movement data would fall outside of the safe region defined by the generic probe envelopes. Therefore, a lawn mower meeting the criteria of any of the generic foot probes would not completely protect any of the participants in the study.

Recommendations for a modification of the UK probe and for further research are discussed.

Power Lawn Mowers: Evaluation of Anthropometric Foot Probe

1.0 Introduction

"Power Mowers", a 1976 Product Profile (1) prepared by the U.S. Consumer Product Safety Commission (CPSC), indicates that an estimated 178 000 power mower-related injuries occurred in 1975. It was estimated that the associated annual costs exceeded 70 million dollars. Over half the total injuries were from body contact with the blade, according to the National Electronic Injury Surveillance System data. The Product Profile also stated that: "Hands and feet were the body parts most frequently injured." In an attempt to reduce the number of blade contact injuries, the CPSC has been considering a proposed safety regulation prepared by Consumers Union (CU) (2) under Section 7 of the Consumer Product Safety Act. The proposed regulation includes two items which are directed at reducing blade contact injuries: a requirement for a dead-man control and a test which utilizes an anthropometric foot probe. The dead-man control requires that the operator maintain continuous contact with the control at the operator position in order to power the blade rotation.

The second requirement, the foot probe test, is intended to protect feet from blade contact by describing a region under the housing through which the blade must not pass. The test assumes two points: first, that the probe or foot simulator is representative of lawn mower users' feet; and second, that the probe test will accurately measure the potential for foot contact with the blade.

CU proposed a probe design (Figure 1) which was an adaptation of an Underwriters' Laboratory (UL) probe. According to telephone conversations with UL personnel, the probe was originally proposed by representatives of lawn mower manufacturers in consultation with shoe manufacturers. The UL representative further indicated that UL modified that probe in an attempt to "make it more severe." CU further modified the probe by adding 1.9 cm to its width.

An evaluation of foot probes by the Human Factors Section of the National Bureau of Standards in the fall of 1975 (3) compared the proposed CU probe with two other generic probes. These were the United Kingdom (UK) probe (Figure 2) designed by the British Standards Institute

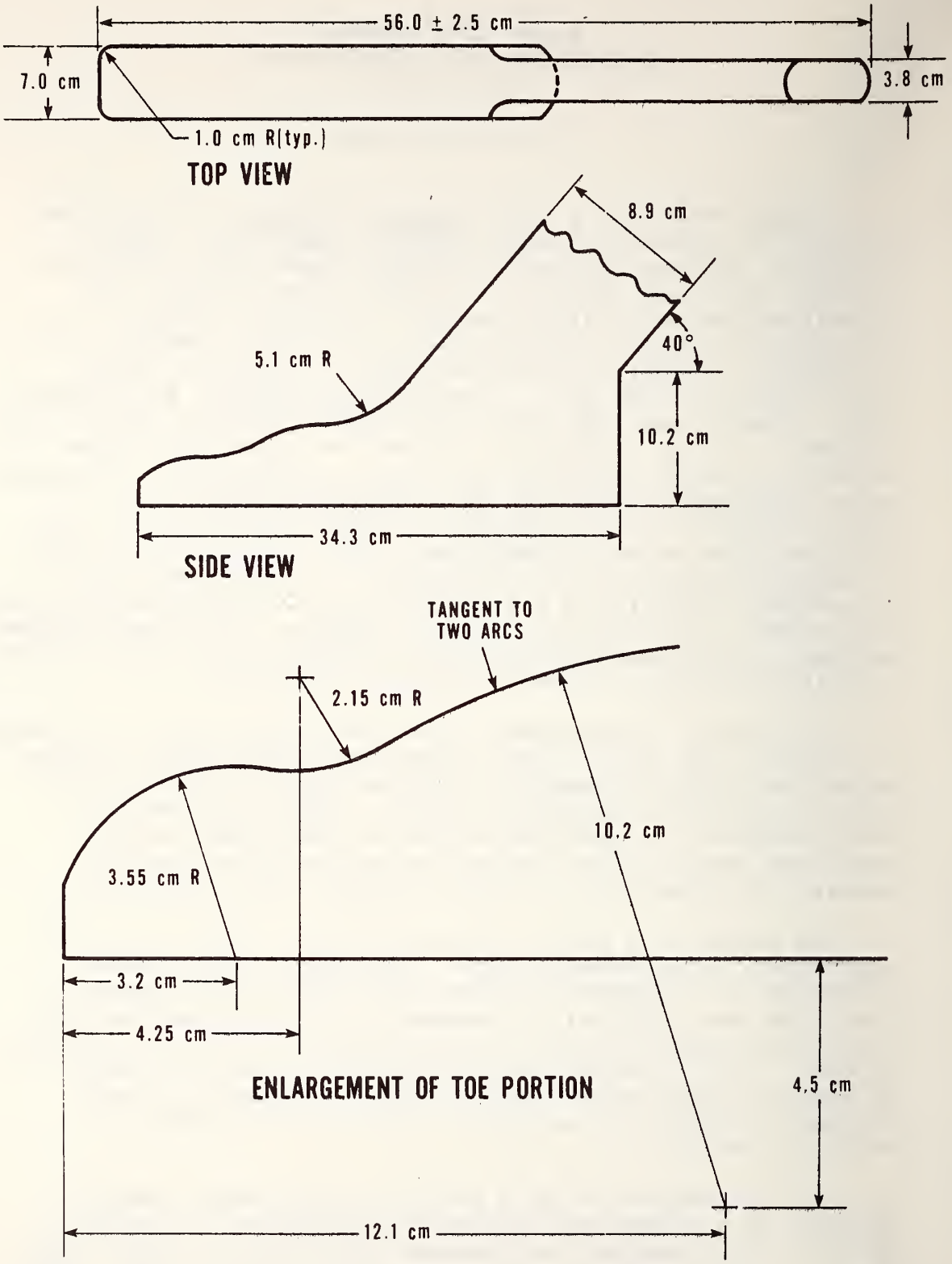

Figure 1. Proposed CU Foot Probe

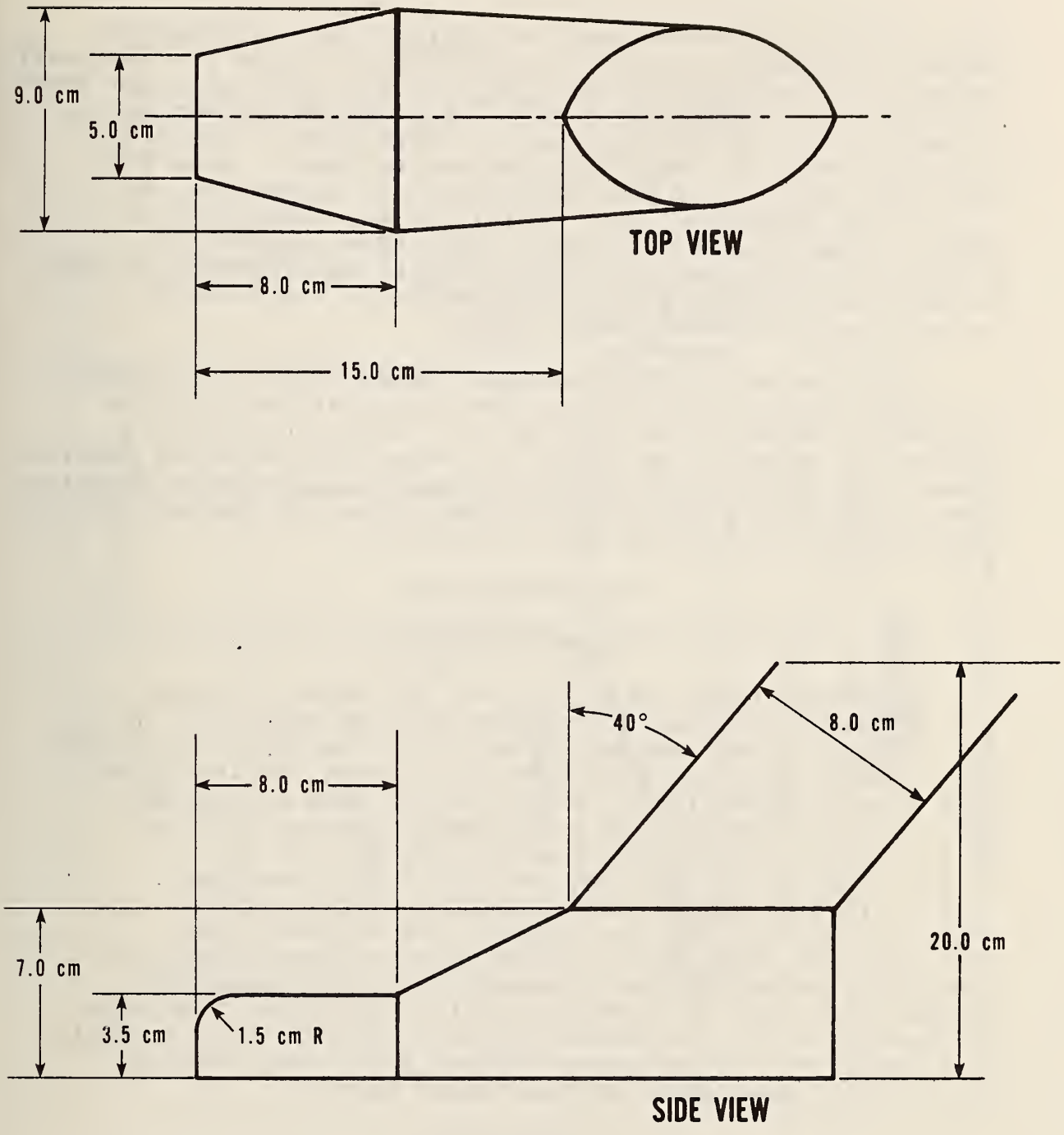

Figure 2. UK Foot Probe

[See Appendix A for Rationale of design.] and the American National Standards Institute (ANSI) probe (Figure 3). The generic probes were compared with nine shoe probes which utilized shoes representing the range of foot sizes from the 5th percentile 11 year old to the 95th percentile adult male. Shoe size data were found by comparing shoe manufacturers' data (4) with foot length data from anthropometric surveys (5, 6, 7, 8). The results of this evaluation were submitted to CPSC in a memo dated October 24, 1975 (See Appendix B). Based on that evaluation, the UK fixture was selected by CPSC as the most representative probe, should a static probe be used for the blade contact test.

In September of 1976 the CPSC requested NBS to develop a further rationale to justify the choice of the UK probe from among the existing foot probes. NBS supported this concept and proposed an effort to compare the existing generic probes (UK, ANSI, and CU) with a sample of lawn mower operators' feet. This report describes the comparison of characteristics under dynamic conditions and the results.

2.0 Methodology

2.1 Participants

The participants in this study included 127 males and 74 females ranging in age from 9 to 66 years ($\bar{X}$ = 32.1, S.D. = 14.9). The mean height was 166.4 cm (S.D. = 13.7 cm). Foot length and breadth measures were taken for the right foot of each participant, both with the shoe on and shoe off. The average foot length without shoe was 25.2 cm (S.D. = 2.2 cm) while the breadth averaged 9.3 cm (S.D. = 0.8 cm). With shoes on, the length averaged 27.2 cm (S.D. = 3.1 cm) and breadth averaged 9.8 cm (S.D. = 1.0 cm). The foot length data without shoes were compared to those collected by other researchers for specific populations (See Appendix C). This comparison demonstrated that the present sample represented the range of foot sizes but not necessarily a statistically representative sample of the frequency various foot sizes would be found in the population of lawn mower users.

2.2 Apparatus

A schematic of the apparatus used in the study is presented in Figure 4. It consisted of two parts: first, a camera and strobe mounted on a platform and focused on a gray-

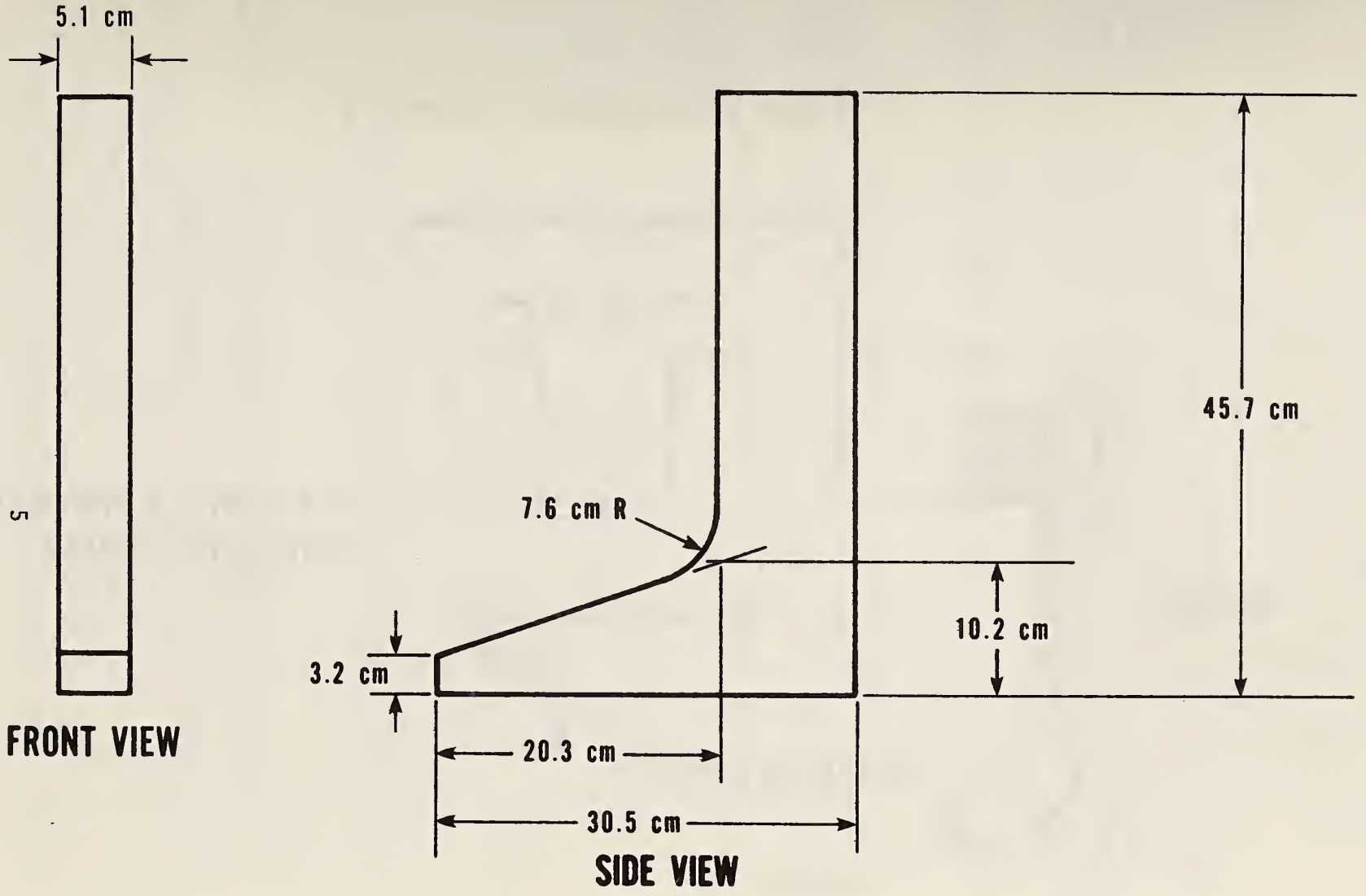

Figure 3. ANSI Foot Probe

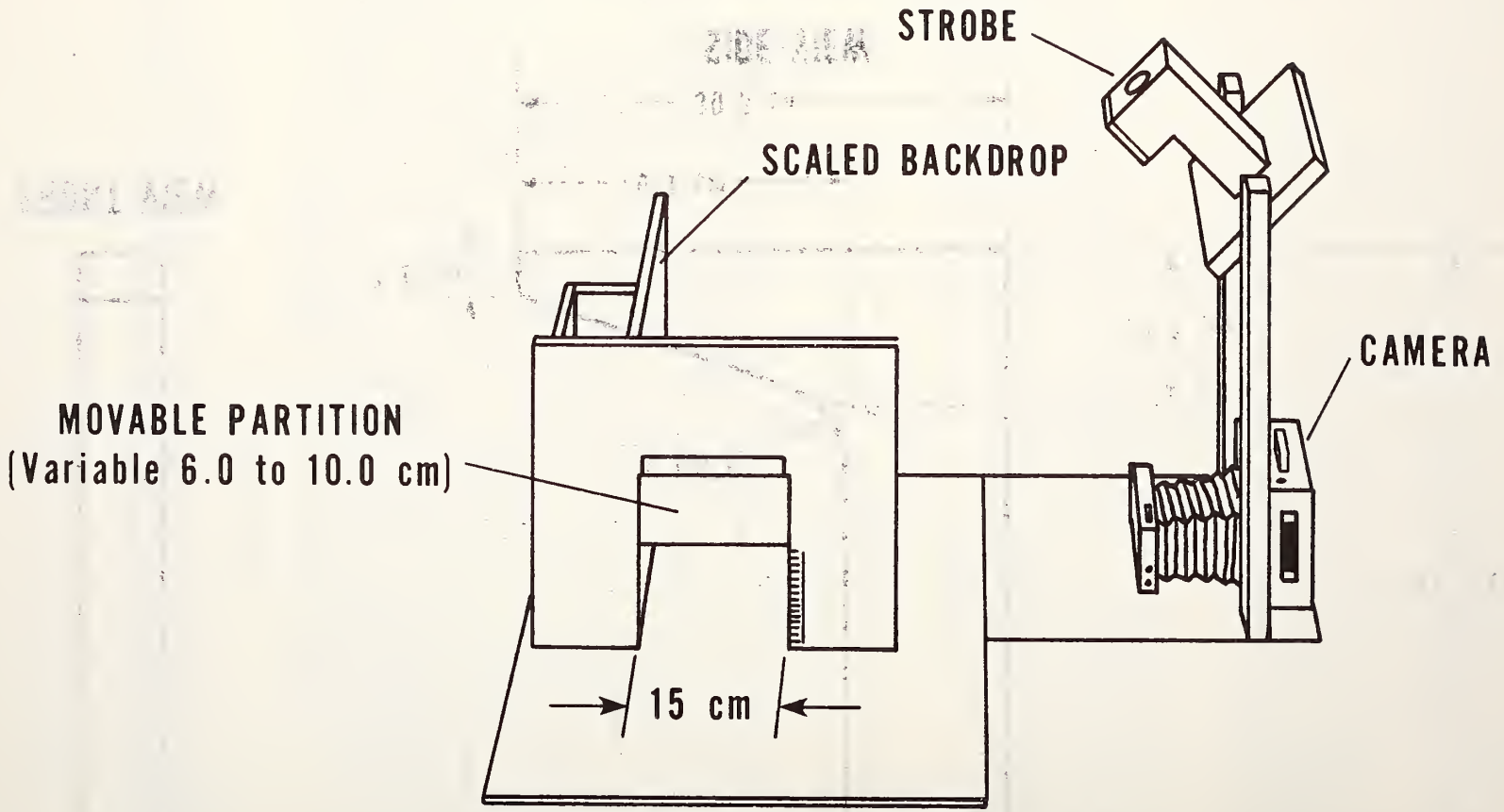

Figure 4. Test Fixture Schematic

on-black, measured graph backdrop. The second part of the apparatus was a frame with a movable metal partition 15.0 cm wide which could be adjusted to allow vertical openings of 6 to 10 cm in 1 cm increments to simulate different housing heights. Perpendicular to the frame was the scaled backdrop. The base of the apparatus was plywood, covered with a 0.5 cm thickness of cushioned carpeting. This test fixture was considered to be an accurate simulator of possible lawn mower configurations (Figure 5 demonstrates the relationship of the simulator to a lawn mower housing). A simulator was chosen to ensure generalizability to lawn mowers as well as other products whose safety or performance might be dependent on foot movement envelopes.

Simple anthropometric scales were used to obtain height and foot length and breadth data.

2.3 Procedure

After signing the appropriate consent forms (See Appendix D), participants removed their shoes, and their height and right-foot length and breadth measures were taken. The sex and age of each subject were also recorded.

The participants then put a white nylon stocking over their right foot to increase image contrast. Participants were then instructed to:

- Insert their right foot under the metal panel as far in and to the left as comfortable, keeping the foot flat on the base. Then,

- Rock the foot back on its heel, lifting the front of the foot as far off the base as possible, curling the toes upward, yet keeping foot as far in as possible.

- Keeping the front of the foot elevated and toes curled up, pull the foot out from under the partition until the base of the toes contacted the metal panel.

At each of the three positions described above, a picture was taken, creating a triple exposure print and negative.

For each participant, foot dimension measurements were taken both with the shoes on and shoes off. Also, triple exposure photographs, one at each of the five housing heights (i.e., 6, 7, 8, 9 and 10 cm), were taken both with shoes on and shoes off. This procedure resulted in ten triple exposure photographs, one exposure at each of the three positions described above, for each participant.

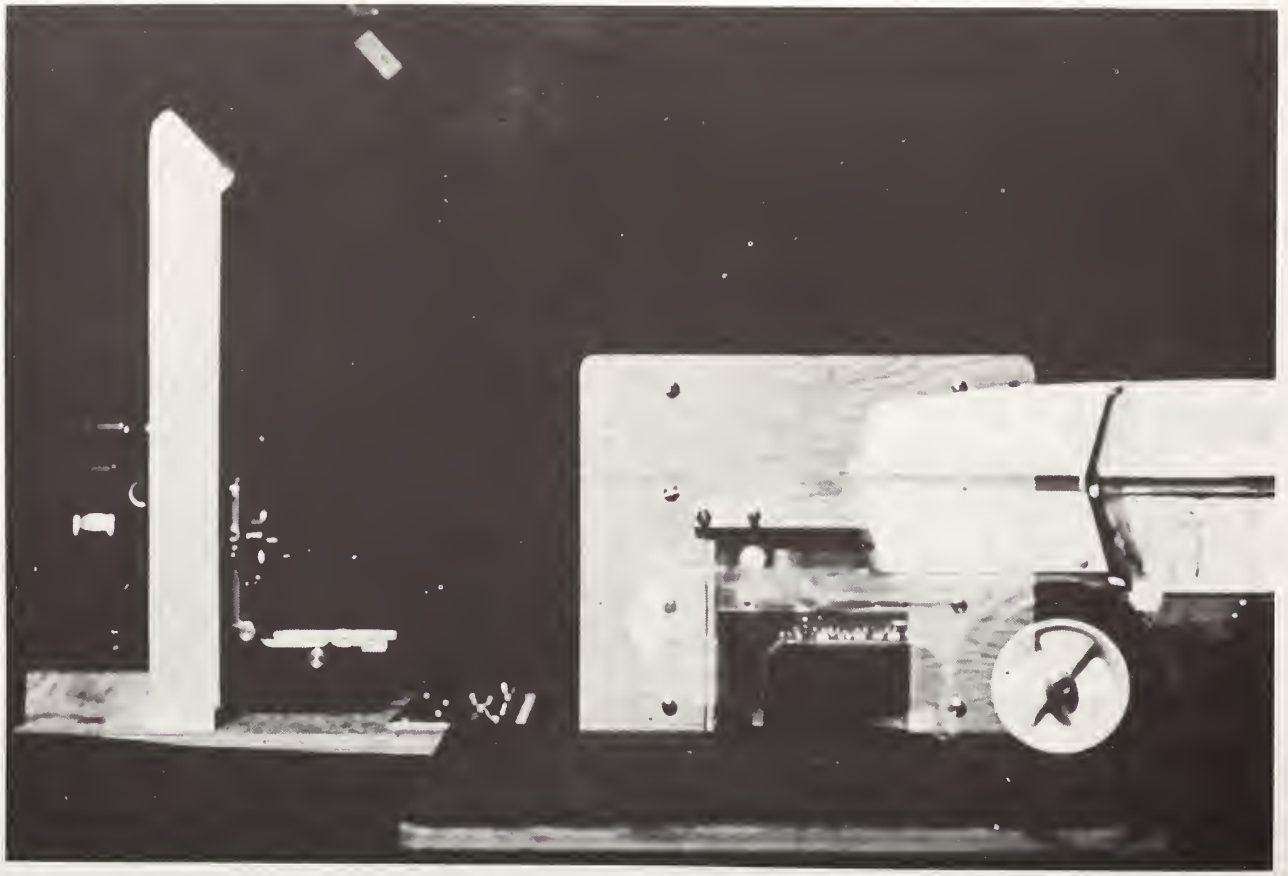

Figure 5. Comparison of Lawn Mower to Simulator

3.0 Results

3.1 Data Reduction

Photographic negatives were placed in an enlarger and projected onto a work board below. For each triple exposure negative, lines on the work board were aligned with reference lines on the photograph created by the scaled backdrop. Next, map pins were placed at the height of the longest point of each of the three positions. (Position 1 was foot flat on floor; Position 2 was foot raised and toes curled; and Position 3 was base of toes contacting the partition.) Map pins were also placed at the point corresponding to the length of the highest point on each image, within 3 cm horizontally of the point described above. There were, therefore, two sets of coordinates for each position or a total of six per negative (housing height). This is illustrated graphically in Figure 6.

Once the map pins were in position, the x and y coordinates (horizontal insertion distance and vertical insertion distance, respectively) for each point were recorded. The same procedure was repeated for each participant at each housing height, both with shoe on and shoe off, resulting in a total of 60 sets of coordinates per participant.

3.2 Data Analysis

It became apparent that data from 6, 8, and 10 cm housing heights would provide adequate information to evaluate the generic probes. For that reason, the 7 and 9 cm housing height data were neither reduced nor analyzed.

Horizontal and vertical insertion distances for the generic probes are presented in Table 1. Table 2 contains the insertion distance data for the foot data. (Refer to Figure 6 for interpretation of column headings.) The foot data are presented in terms of Median, 5th percentile and 95th percentile for the actual sample, not statistically derived. Other percentiles can be derived from raw data if desired. These data were used to develop safety envelopes for each housing height and for shoe-on and shoe-off data individually. The envelopes are presented in Figures 7 through 9 for the generic probes and Figures 10 through 15 for the foot data. In addition, the 95th percentile foot data are compared with the generic probes in Figures 16 through 18. It should be noted that the 5th percentile x coordinate data were used in all cases when graphing position 3H (See Figure 6) in order to demonstrate the most severe safety envelope; thus, the discrepancies between Table 2 and the Figures 10 through 18.

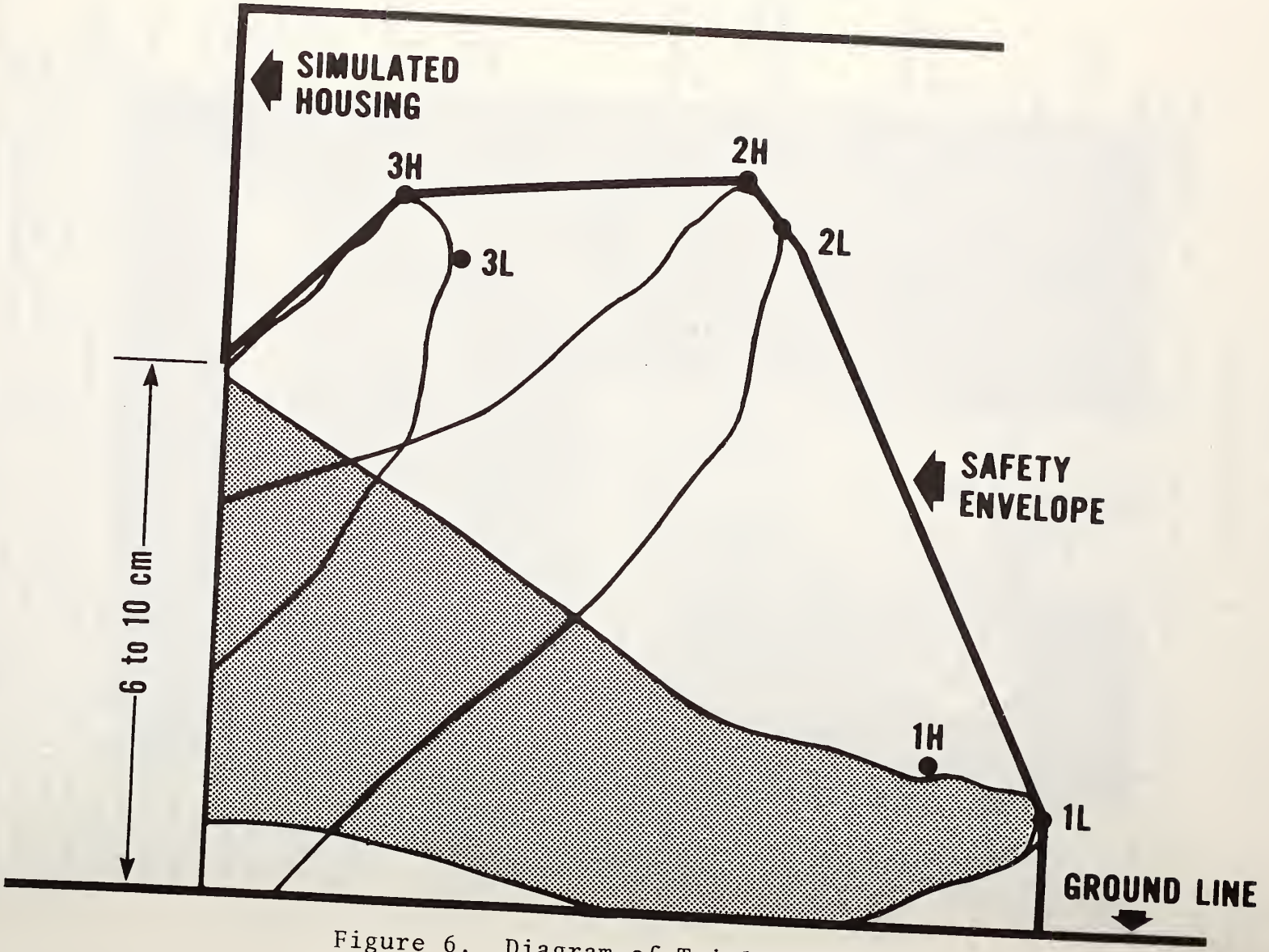

Figure 6. Diagram of Triple Exposure Foot Image

Table 1

Generic Probe Data

	Position *1				Position 2				Position 3			
	L		H		L		H		L		H	
	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
Housing Height	cm	cm	cm	cm	cm	cm	cm	cm	cm	cm	cm	cm
6 cm												
ANSI	6.0	1.6	5.9	3.9	6.0	1.6	5.9	3.9	4.1	2.2	3.9	5.0
CU	7.5	2.1	5.5	4.2	7.5	2.1	5.5	4.2	4.8	4.1	2.7	5.6
UK	11.4	2.6	10.5	3.6	11.4	2.6	10.4	4.0	8.4	5.1	6.8	6.4
8 cm												
ANSI	11.6	1.7	11.3	3.6	11.2	1.7	11.0	4.0	7.2	4.0	6.8	6.3
CU	20.8	1.4	17.5	4.0	20.5	2.8	17.0	5.8	5.8	6.0	3.2	8.0
UK	15.5	2.0	13.7	4.5	15.5	2.0	13.8	5.1	8.5	8.0	7.0	9.5
10 cm												
ANSI	16.8	1.3	16.3	3.8	16.2	2.8	16.0	5.1	8.1	6.1	7.8	8.0
CU	22.6	1.5	19.0	4.3	22.1	6.2	18.5	10.0	6.3	8.1	3.9	9.8
UK	16.4	2.1	14.7	3.9	16.1	5.3	14.5	7.7	8.8	8.4	6.6	11.3

* Refer to Figure 6

Table 2

Foot Data (cm)

	Position* 1				Position 2				Position 3			
	L		H		L		H		L		H	
	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
Housing Height												
6 cm with shoe												
5th %ile	5.2	0.8	4.0	2.8	4.3	2.4	2.8	4.5	2.3	2.3	0.8	4.8
median	8.0	2.1	6.5	4.4	7.1	4.6	5.2	6.7	5.2	4.7	3.1	6.6
95th %ile	10.3	4.7	9.2	6.8	9.3	7.7	7.5	9.5	8.0	8.1	5.7	9.6
6 cm without shoe												
5th %ile	7.5	0.5	5.4	1.7	4.3	4.0	3.1	5.4	1.5	5.7	0.4	7.0
median	10.2	1.6	8.3	2.7	7.3	6.8	6.0	8.1	3.8	7.7	2.5	8.9
95th %ile	12.0	4.4	10.8	5.5	9.9	10.5	8.6	11.5	6.1	11.2	4.6	11.8
8 cm with shoe												
5th %ile	7.4	1.4	5.8	3.5	6.6	3.8	4.4	6.0	2.9	5.1	1.1	7.4
median	10.4	2.3	8.3	4.4	9.3	6.0	7.0	8.1	5.9	7.0	3.5	9.0
95th %ile	12.7	4.4	10.6	6.5	11.4	9.2	9.2	10.6	8.0	9.5	6.0	10.6
8 cm without shoe												
5th %ile	9.5	1.2	7.0	2.3	6.7	5.4	5.6	6.6	2.0	7.7	0.7	8.8
median	13.4	1.9	10.9	2.9	10.7	7.2	9.7	8.5	4.0	9.8	2.6	10.9
95th %ile	15.1	4.0	12.6	5.3	13.4	10.0	12.3	11.0	6.5	11.7	5.5	12.7
10 cm with shoe												
5th %ile	9.8	0.9	6.9	3.3	7.8	4.0	4.6	6.4	3.1	7.5	1.2	10.3
median	13.4	1.8	11.1	4.4	11.8	7.2	9.5	9.4	6.2	10.3	3.7	11.9
95th %ile	16.1	3.2	13.7	5.8	15.0	10.6	12.5	12.4	9.1	12.2	6.6	13.7
10 cm without shoe												
5th %ile	12.3	1.0	9.2	2.1	8.3	7.4	6.6	9.8	2.1	10.6	0.9	11.5
median	15.7	1.6	12.9	2.9	11.3	11.7	10.0	12.9	3.9	12.2	2.5	13.4
95th %ile	17.8	2.4	15.5	3.7	14.4	13.6	13.0	14.8	6.0	13.8	4.7	15.0

* Refer to Figure 6.

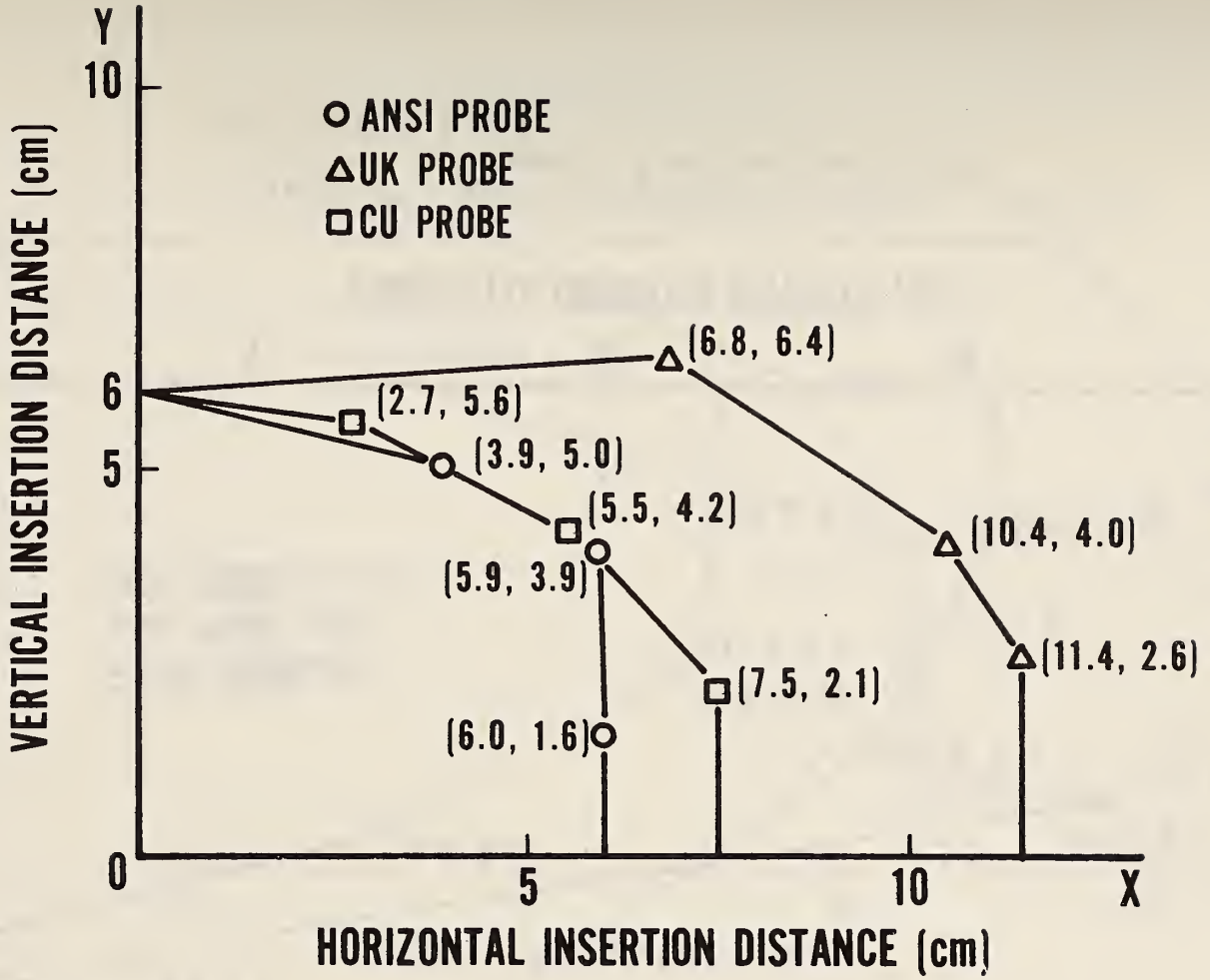

Figure 7. Safety Envelopes--Generic Probes - 6 cm Housing Height

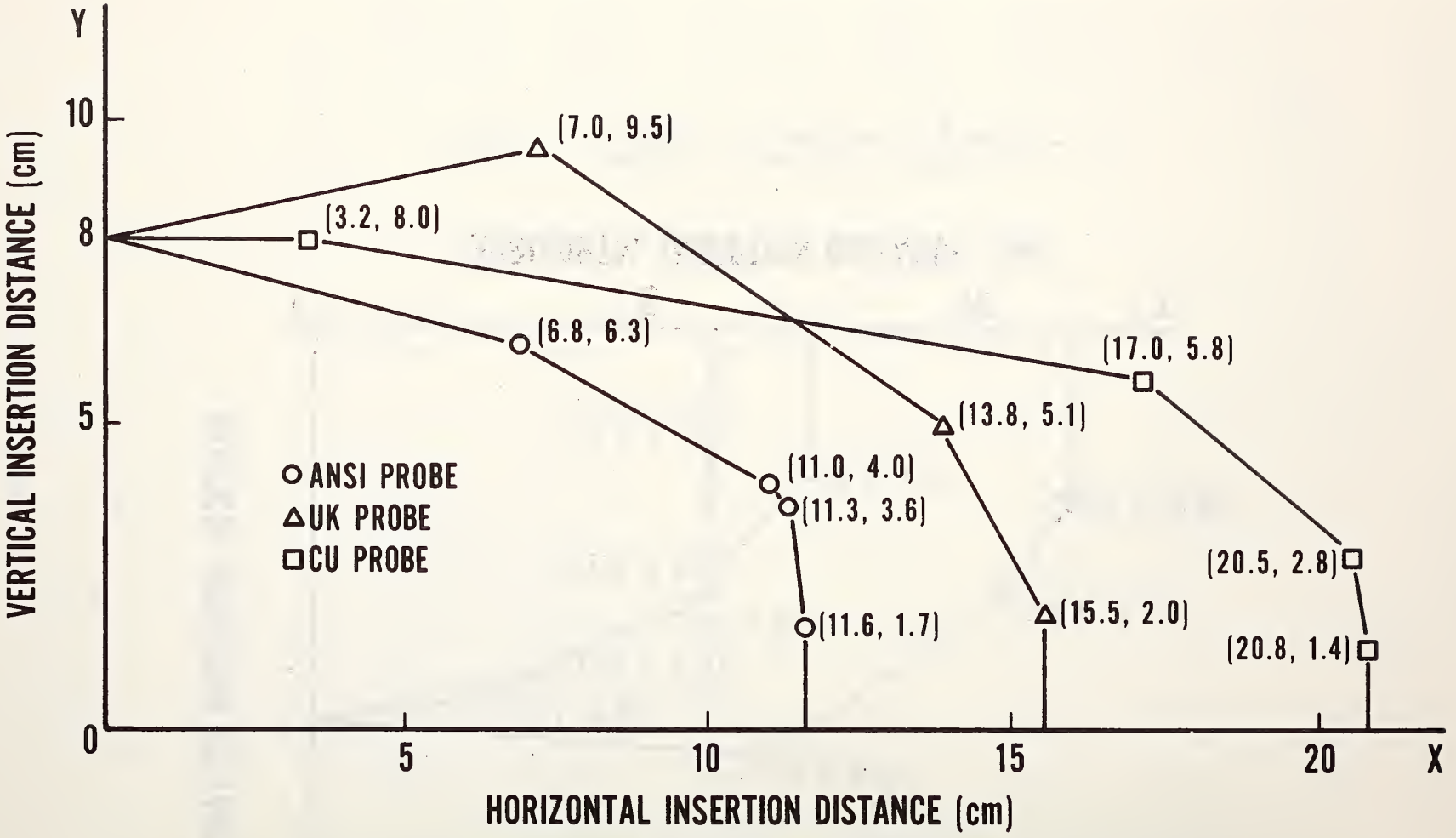

Figure 8. Safety Envelopes--Generic Probes - 8 cm Housing Height

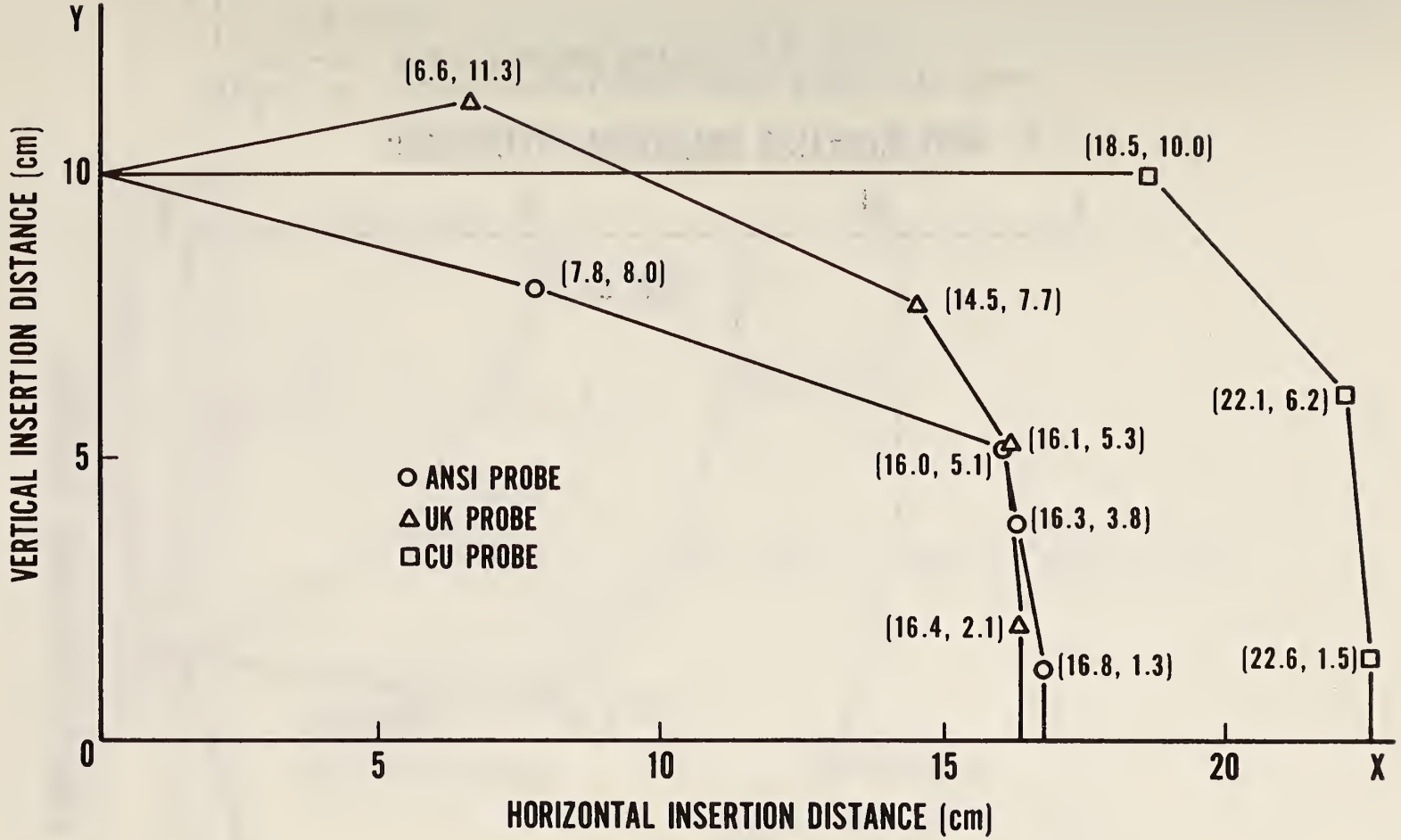

Figure 9. Safety Envelopes--Generic Probes - 10 cm Housing Height

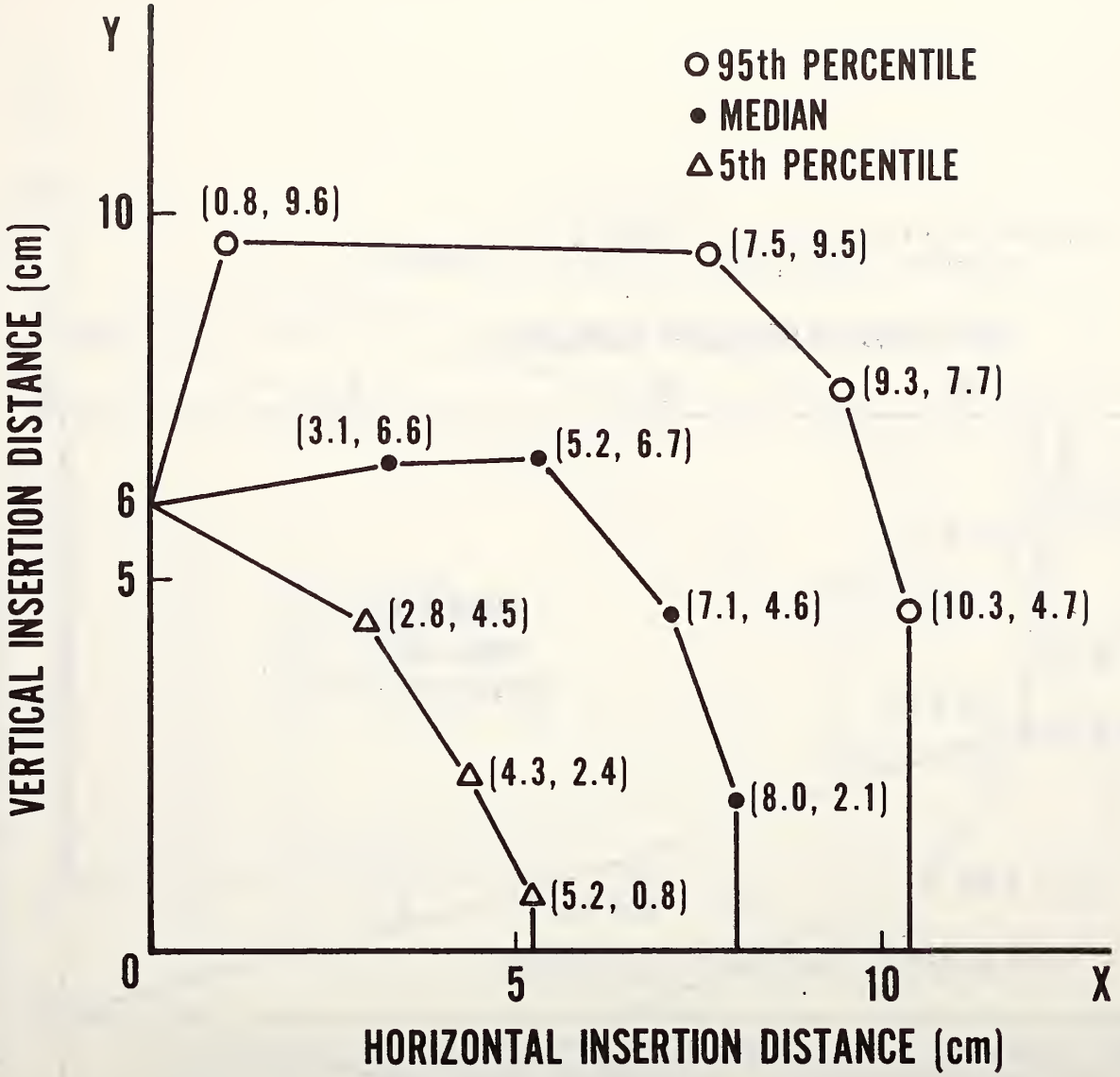

Figure 10. Safety Envelopes--Foot Data-With Shoe 6 cm Housing Height

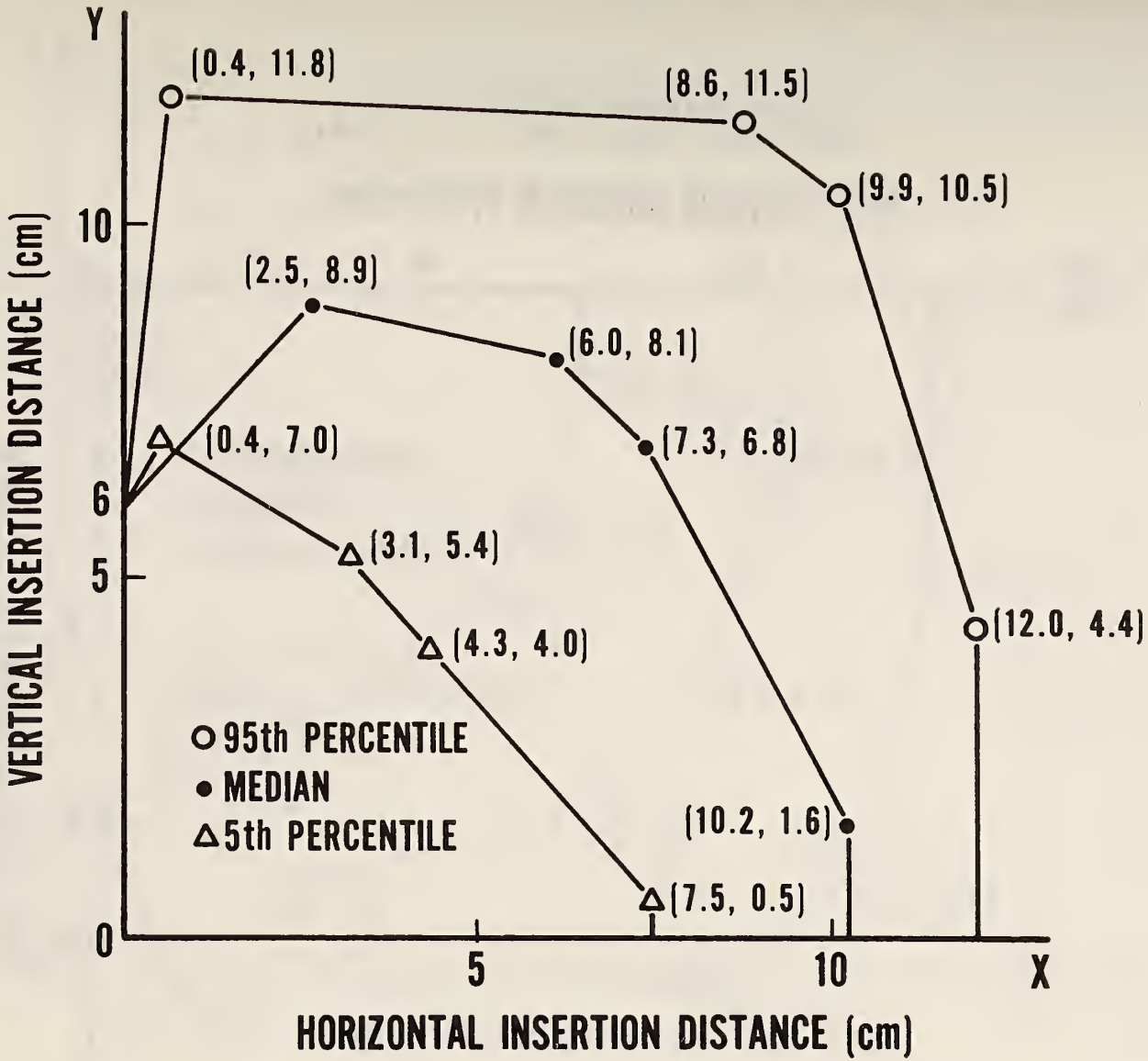

Figure 11. Safety Envelopes--Foot Data-Without Shoe
6 cm Housing Height

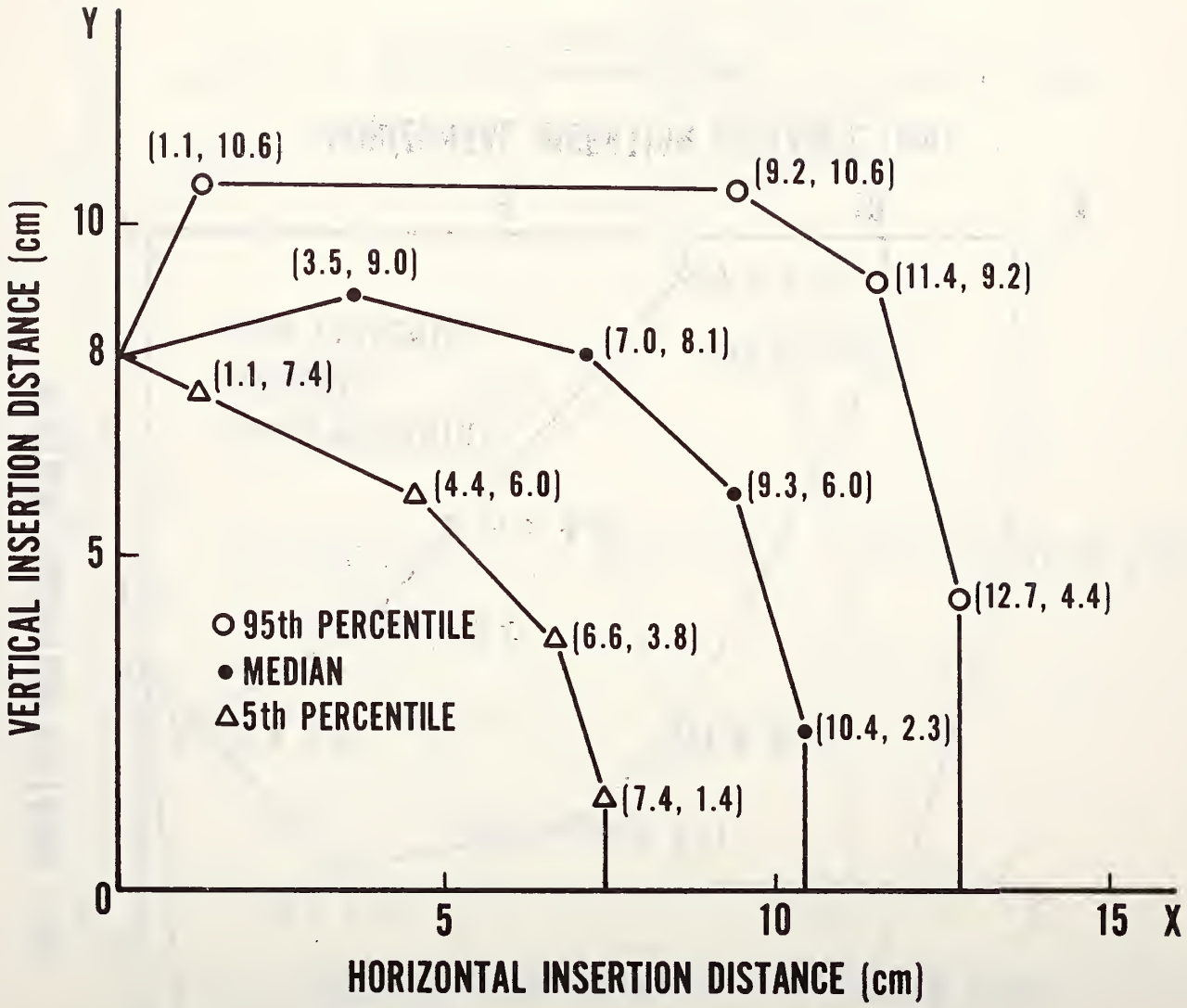

Figure 12. Foot Data--With Shoe
8 cm Housing Height

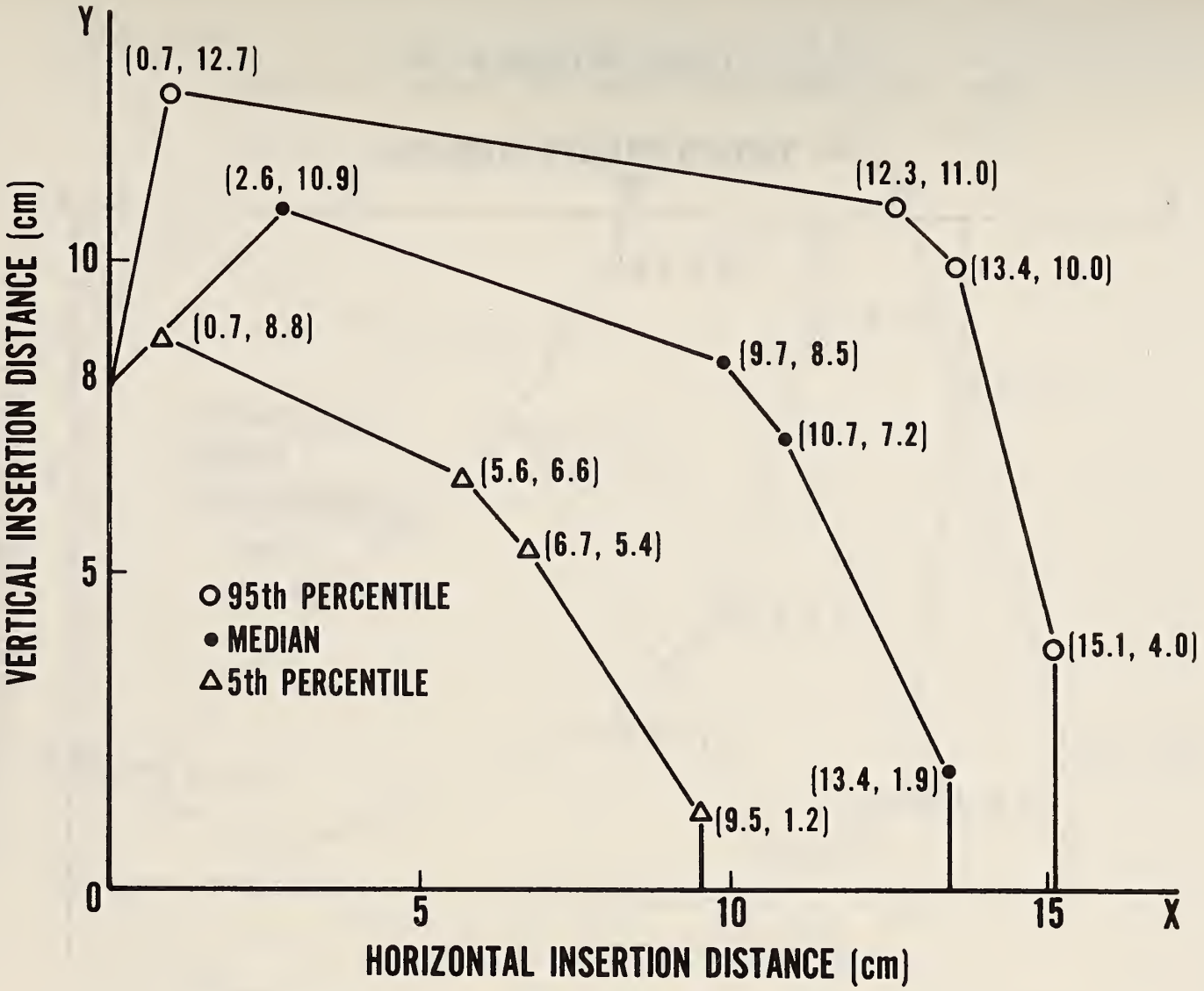

Figure 13. Safety Envelopes--Foot Data-Without Shoe
8 cm Housing Height

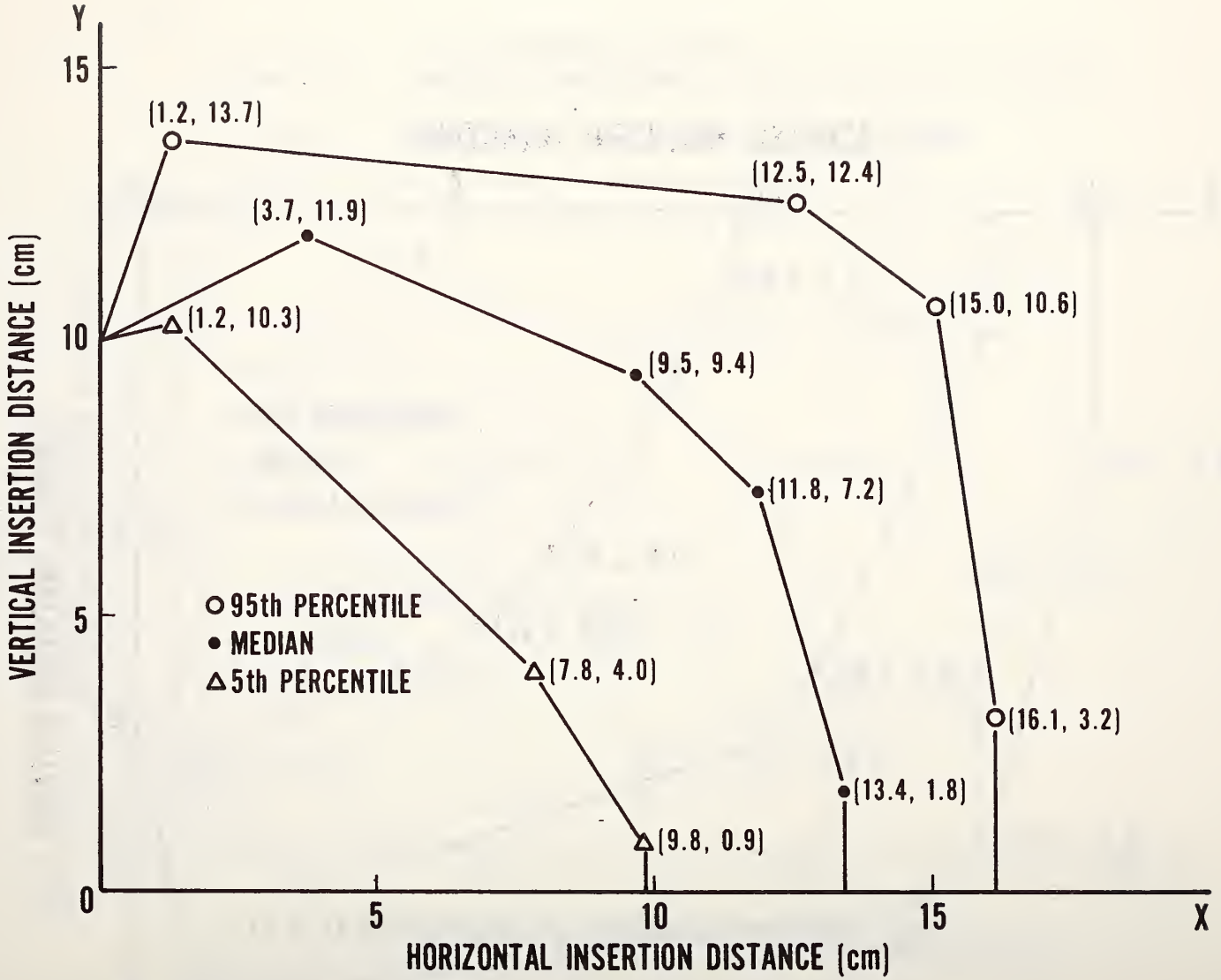

Figure 14. Safety Envelopes--Foot Data-With Shoe
10 cm Housing Height

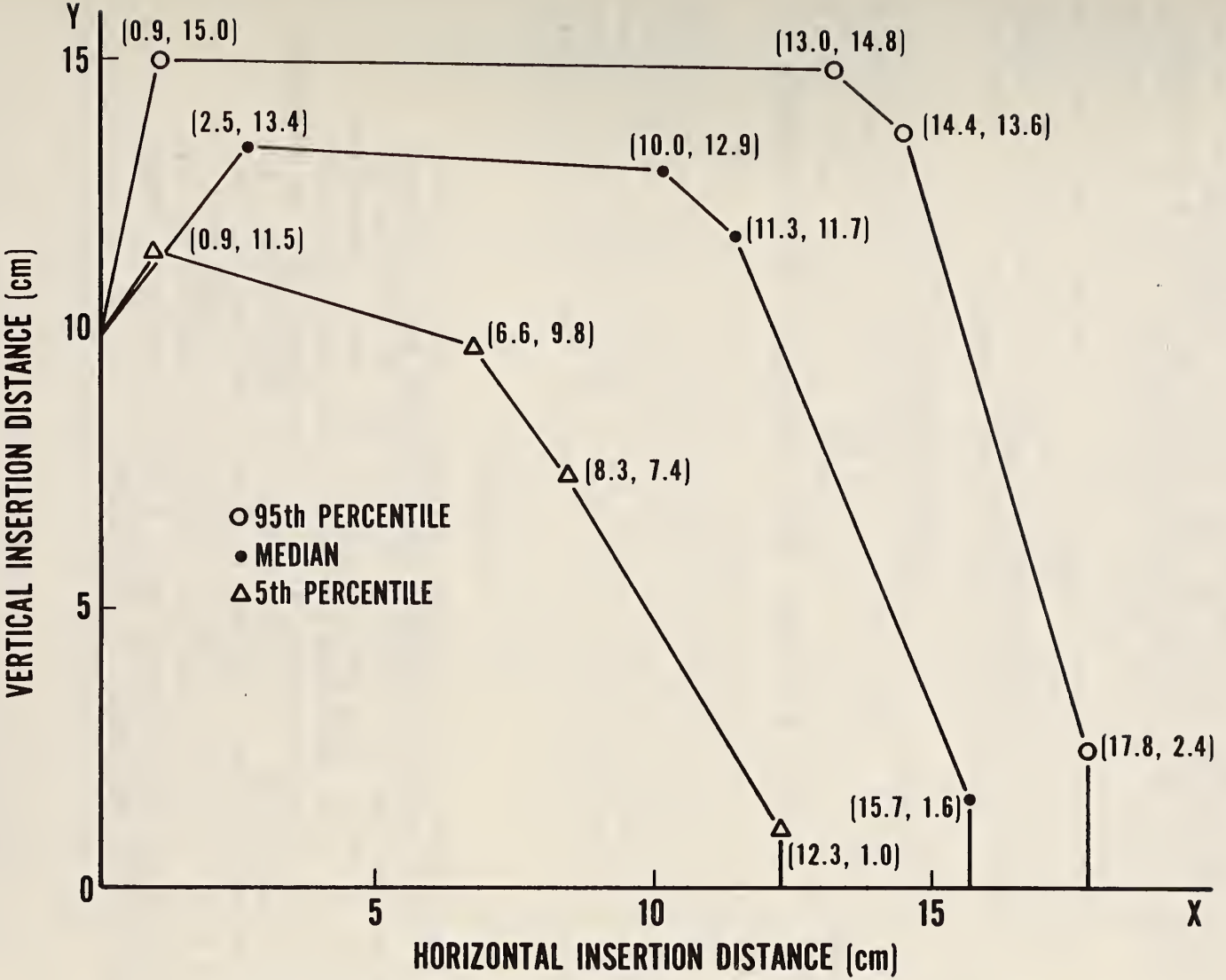

Figure 15. Safety Envelopes--Foot Data-Without Shoe
10 cm Housing Height

In addition to comparing envelopes defined by the aggregate foot data with the generic probe data, a comparison of individual participant's data was made with each generic probe to determine the percentage of participants who would be completely protected by each generic probe. This result is presented in Table 3. *These data indicate that at least one point of each individual's foot movement data would fall in the hazardous region* as determined by the corresponding point of the generic probe data. *Therefore, none of the three generic probes would completely protect any of the participants in the study.*

Table 3

Percentage of Sample
Protected by the Generic Probes

Shoe Condition	Housing Height					
	6 cm		8 cm		10 cm	
Probe	With	Without	With	Without	With	Without
ANSI	0	0	0	0	0	0
CU	0	0	0	0	0	0
UK	0	0	0	0	0	0

4.0 Discussion

Inspection of the safety envelopes indicates that of the three generic probes, the UK probe most closely approximates the foot data at 6, 8, and 10 cm housing heights. However, the percentage of the sample protected is far less than the 95th percentile envelope for real feet--which is recommended as the lower bound for an adequate safety regulation. If a probe were designed using the 95th percentile data, theoretically 95 percent of the tested population would be protected from blade contact. Conversely, if the probe were designed based on the 5th percentile or Median data, only 5 or 50 percent, respectively, of the population would be protected.

Inspection of Figures 10 through 15 indicates that in all cases the Median and 95th percentile envelopes pass through a region higher than the bottom edge of the housing position. However, Figures 7 through 9 indicate that the UK probe is the only probe which passes through the region above the bottom edge of the housing. In this respect, only the UK probe might provide protection for the operator, but that protection is very limited. Further, inspection of Figures 16 through 18 demonstrates that none of the probes approaches the vertical insertion distances achieved by the 95th percentile foot data. The CU probe exceeds the other probes and the foot data in terms of horizontal insertion distances; however, in accordance with existing standards, the blade is required to rotate above the lower edge of the housing. Consequently, CU's longer horizontal insertion distance does not result in any added protection of the operator from blade contact.

If the UK probe is selected by CPSC for inclusion in the Standard, one minor modification is suggested as a means to assure repeatability of the test. That is, the back of the heel of the probe should be flat and parallel to the front of the toe (Figure 19). This will allow for consistent vertical rotation, not now possible.

It must be noted that a serious problem is still present with all of the existing generic probes. Namely, the comparison of the individual participant data with the generic probe data indicates that none of the participants would be completely protected by any of the probes. In contrast, a probe based on the 95th percentile data would protect a larger percentage of the population, as indicated in Table 4.

Table 4

Percentage of Sample
Protected by 95th Percentile Data

Shoe Condition	Housing Height 6 cm	8 cm	10 cm
With	77%	82%	74%
Without	80%	78%	73%

Table 4 shows that the 95th percentile data protects less than 95 percent of the population, as might be assumed. However, the percentile data is an aggregation over all participants and is not directly related to any one particular foot. The dynamic characteristics of feet under a barrier do not conform to normal statistical assumptions. To further demonstrate this, a sample of correlation

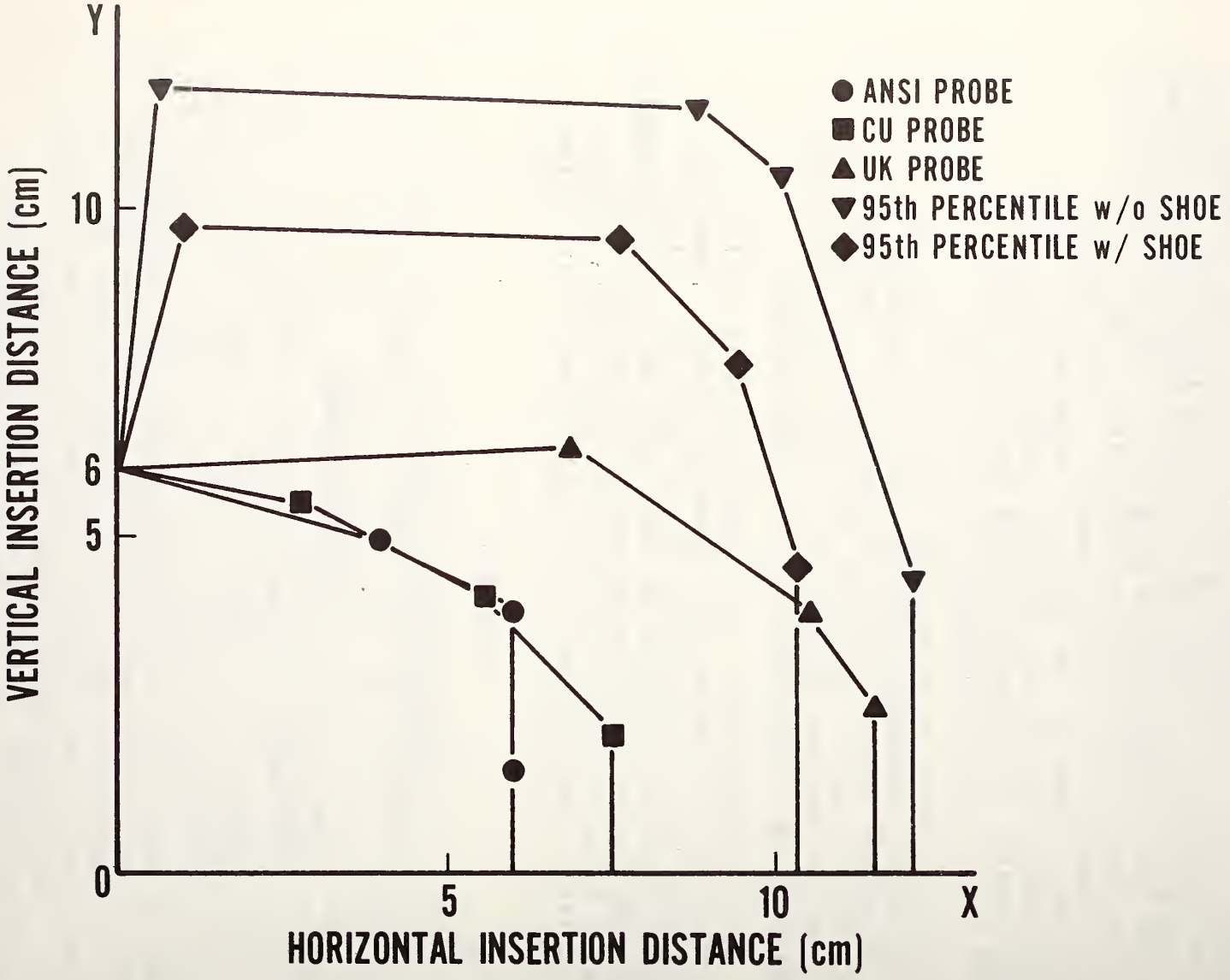

Figure 16. Safety Envelopes--Comparison Data
6 cm Housing Height

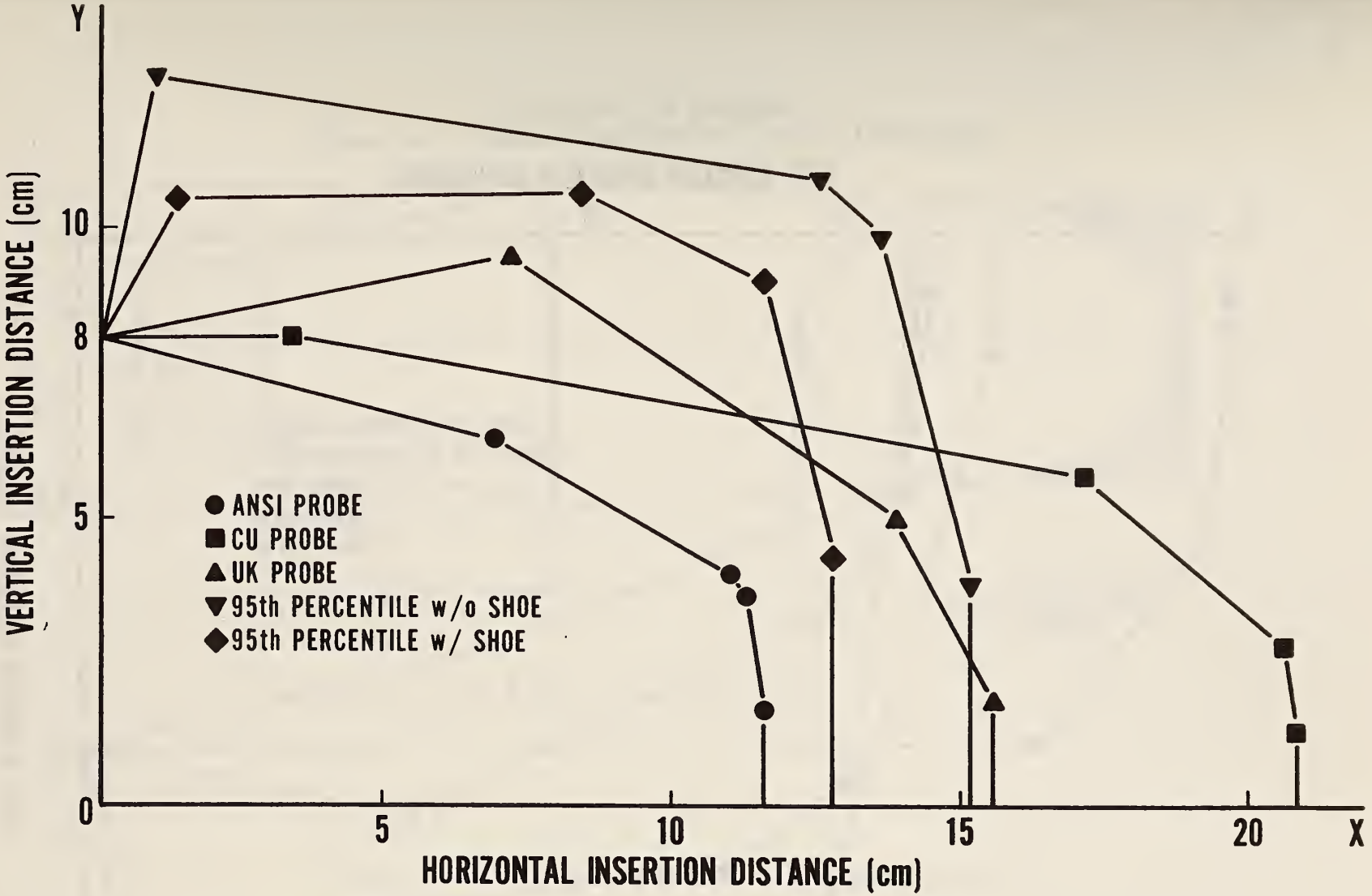

Figure 17. Safety Envelopes--Comparison Data
8 cm Housing Height

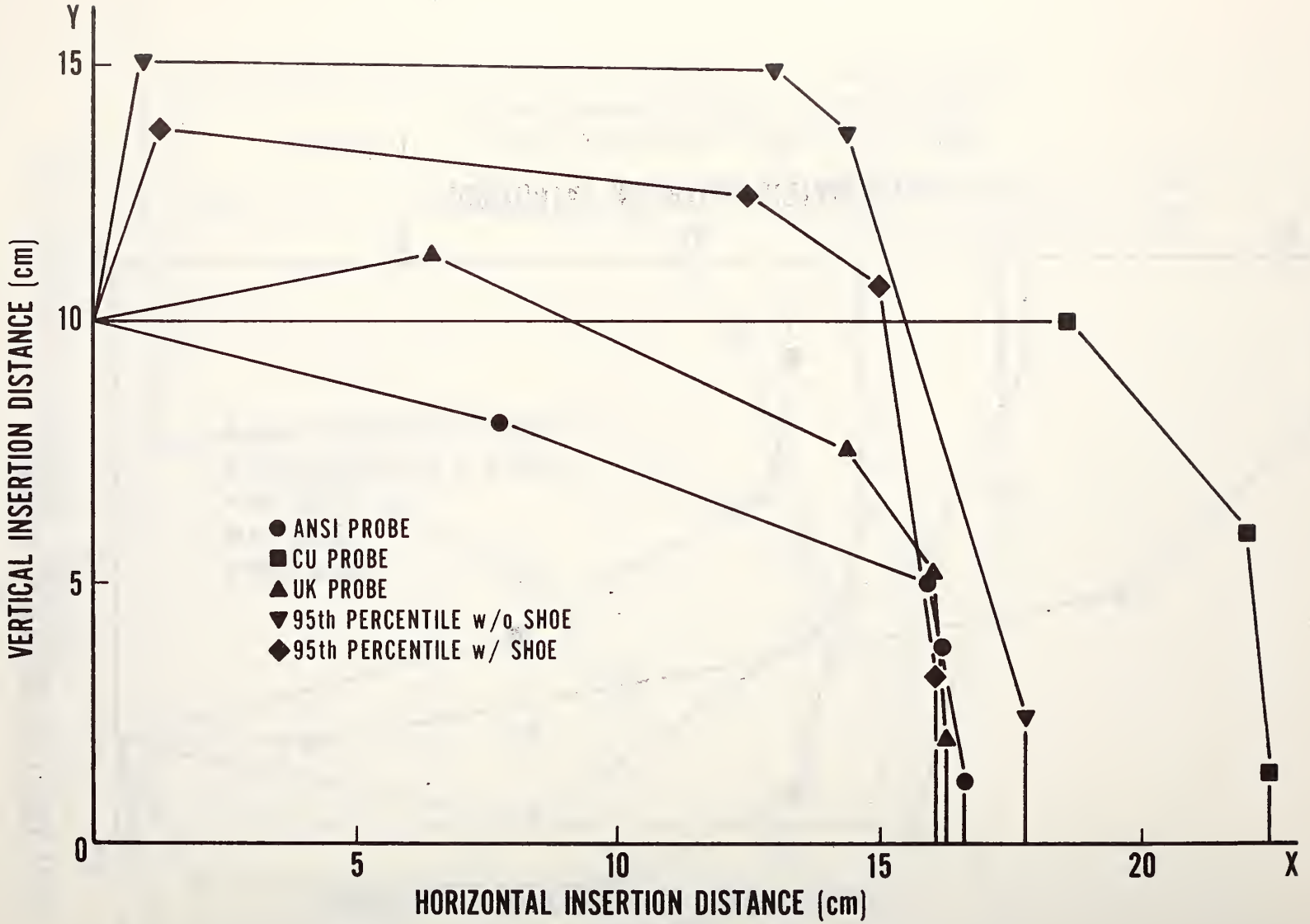

Figure 18. Safety Envelopes--Comparison Data
10 cm Housing Height

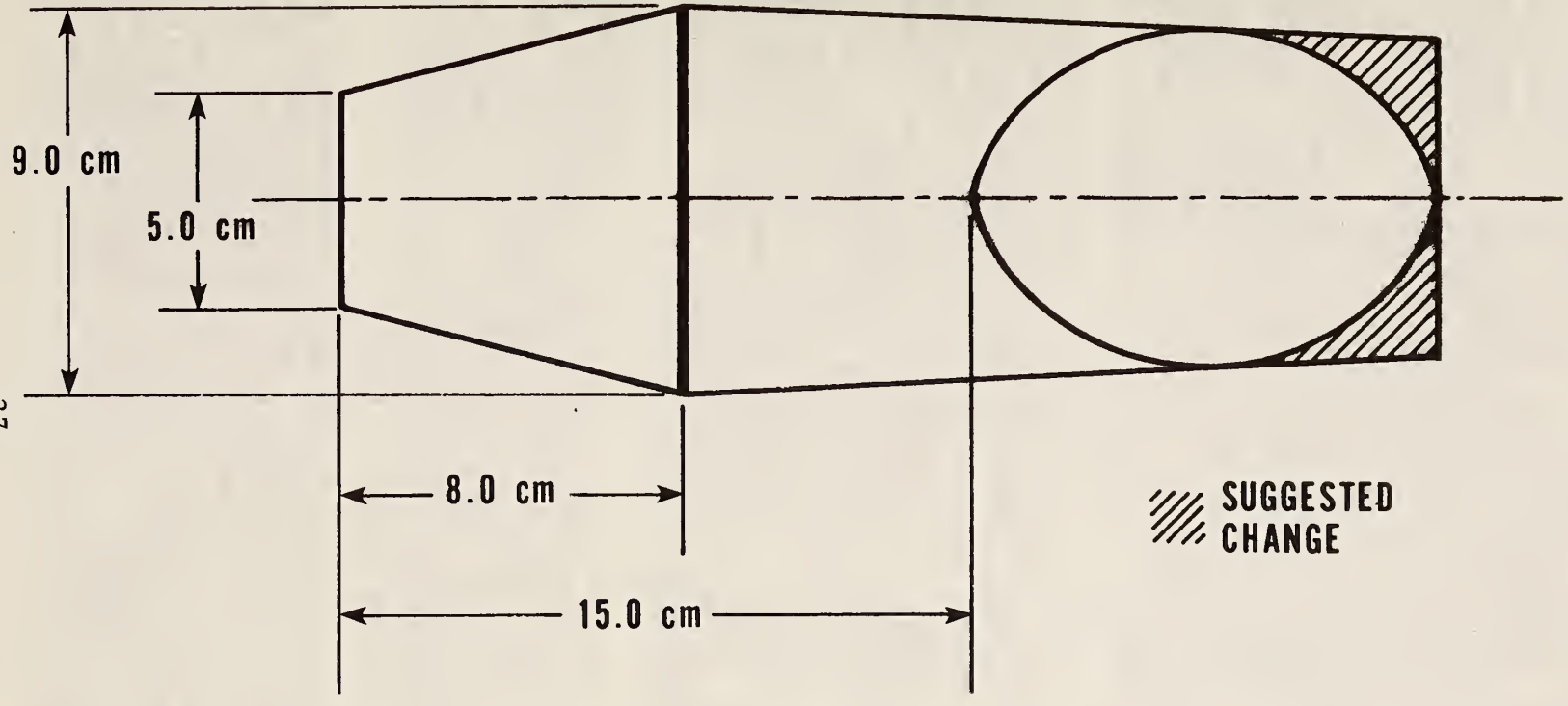

Figure 19. Proposed Modification of UK Probe

coefficients (9) were calculated for some of the data; these are presented in Table 5. Inspection of Table 5 suggests that there are at least two factors affecting the foot movement envelopes. The first may be referred to as length, or horizontal insertion, and is demonstrated by the high positive relationships between 1LX and 2LX. The second factor might be referred to as flexibility, or vertical insertion, and is demonstrated by the high positive relationships between 2HY and 3HY. These two factors do not appear to be systematically related to each other, as demonstrated by the correlations 1LX-2HY, 1LX-3HY, and 2LX-3HY, or may even be negatively related as indicated by the correlations between 2LX and 2HY. A more thorough analysis of these data was beyond the scope of the present project. However, the data indicate that such analyses should be done in the near future along with the data from the 7 and 9 cm housing heights.

The scope of the present project was to evaluate the existing generic probes. However, in an attempt to demonstrate the possible effectiveness of alternatives to the generic probes, one of the shoe probes developed for an earlier study (3) was tested using the simulator. The probe selected was Shoe Probe "I", which was constructed from the 95th percentile size adult female shoe. The results are presented in Table 6 and graphically in Figures 20, 21, and 22. It should be noted that this shoe probe passes through more of the region above the housing plane than even the UK probe. Further, the data from Shoe Probe "I" was compared against the individual foot data to determine the percentage of the sample protected. The results are presented in Table 7.

As can be seen in Table 7, the results associated with Shoe Probe "I" are not particularly impressive when compared to the 95th percentile data although they exceed the protection offered by any of the generic probes. It should be noted that Shoe Probe "I" is not, at this point, being recommended for inclusion in a standard. Rather, this demonstrates only one of many possible alternatives to the proposed generic probes.

It is clear from all of the above that further research should be performed to develop a more protective probe. The present data clearly demonstrate that *none of the existing generic probes comes close to matching a safest case for foot data*. A determination of adequacy of the sample with regard to population demographics and distribution is warranted. If required, a larger and more diverse sample should be tested. A probe or probes could be developed to match the data collected and validation of those probes accomplished.

Table 5

Sample Correlations

Correlates	Housing Height: With Shoe 6cm	With Shoe 8cm	With Shoe 10cm	Without Shoe 6cm	Without Shoe 8cm	Without Shoe 10cm
FL**-1LX	.32*	.37*	.57*	-.05	.06	.46*
FL-2LX	.17	.30*	.46*	-.24*	.04	.46*
FL-2HY	.24*	.24*	-.04	.50*	-.07	-.15
FL-3HY	.19*	.09	.10	.33*	.12	.23*
1LX-2LX	.86*	.92*	.90*	.75*	.80*	.73*
1LX-2HY	.19*	.02	.01	-.15	-.12	.14
1LX-3HY	.23*	.14	.42*	0	.03	.39*
2LX-2HY	.14	-.23*	-.34*	-.57*	-.51*	-.32*
2LX-3HY	.13	0	.26*	-.29	-.22*	.07
2HY-3HY	.75*	.53*	.29*	.75*	.55*	.37*

* $p < .05$ FL With Shoe - FL Without Shoe r = .75*

** Foot length

Table 6

Shoe Probe "I" Data

Housing Height	L x	L y	H x	H y
Position 1*				
6 cm	11.3	2.8	9.4	4.5
8 cm	13.6	2.4	11.1	5.6
10 cm	15.6	5.3	11.9	8.3
Position 2				
6 cm	10.6	5.3	8.7	6.6
8 cm	12.3	8.0	9.4	10.5
10 cm	14.1	10.3	10.9	12.8
Position 3				
6 cm	7.1	4.3	5.2	6.1
8 cm	8.1	6.0	4.9	8.8
10 cm	9.2	10.9	5.7	13.3

*Refer to Figure 6

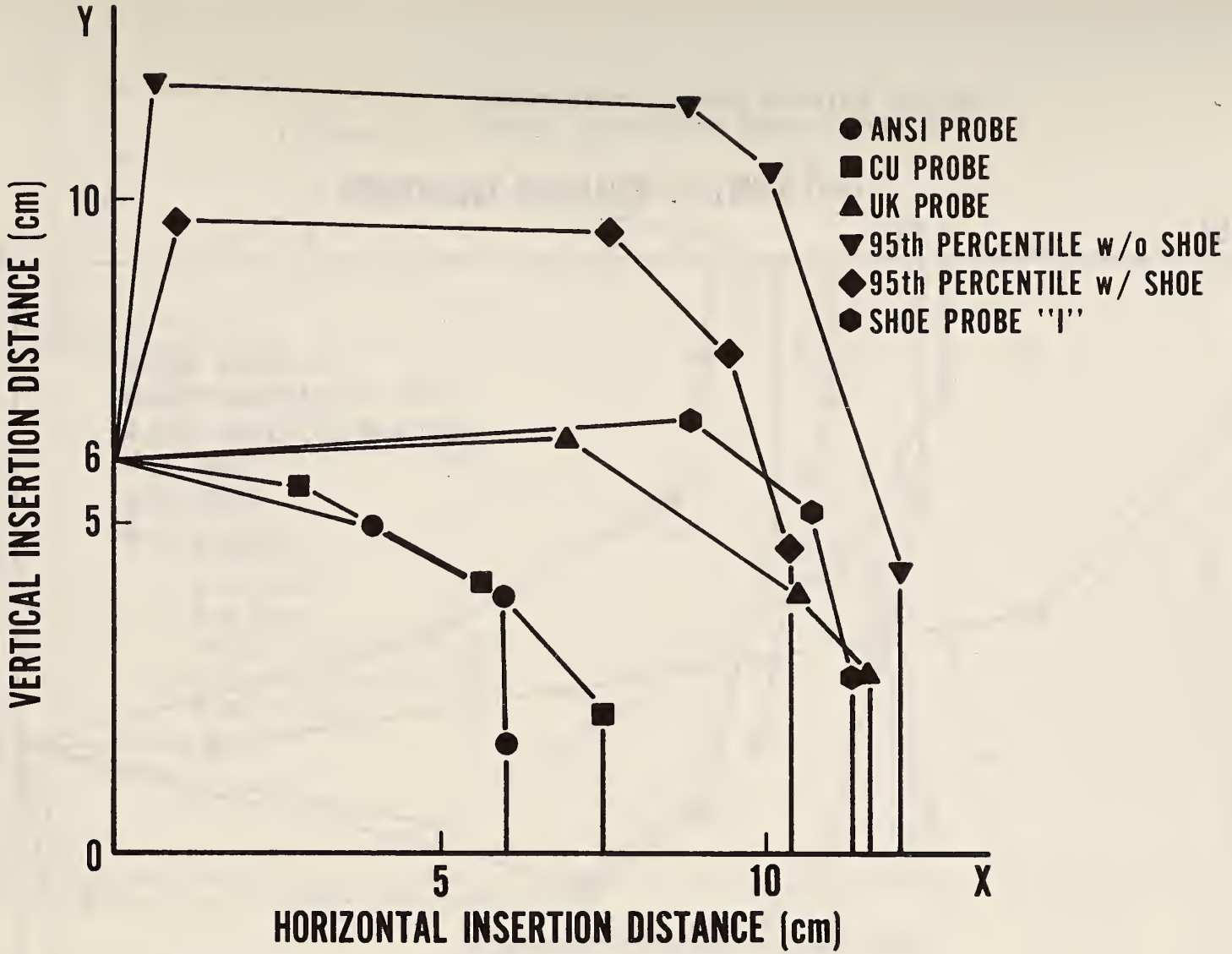

Figure 20. Safety Envelopes--Shoe Probe I Comparison - 6 cm Housing Height

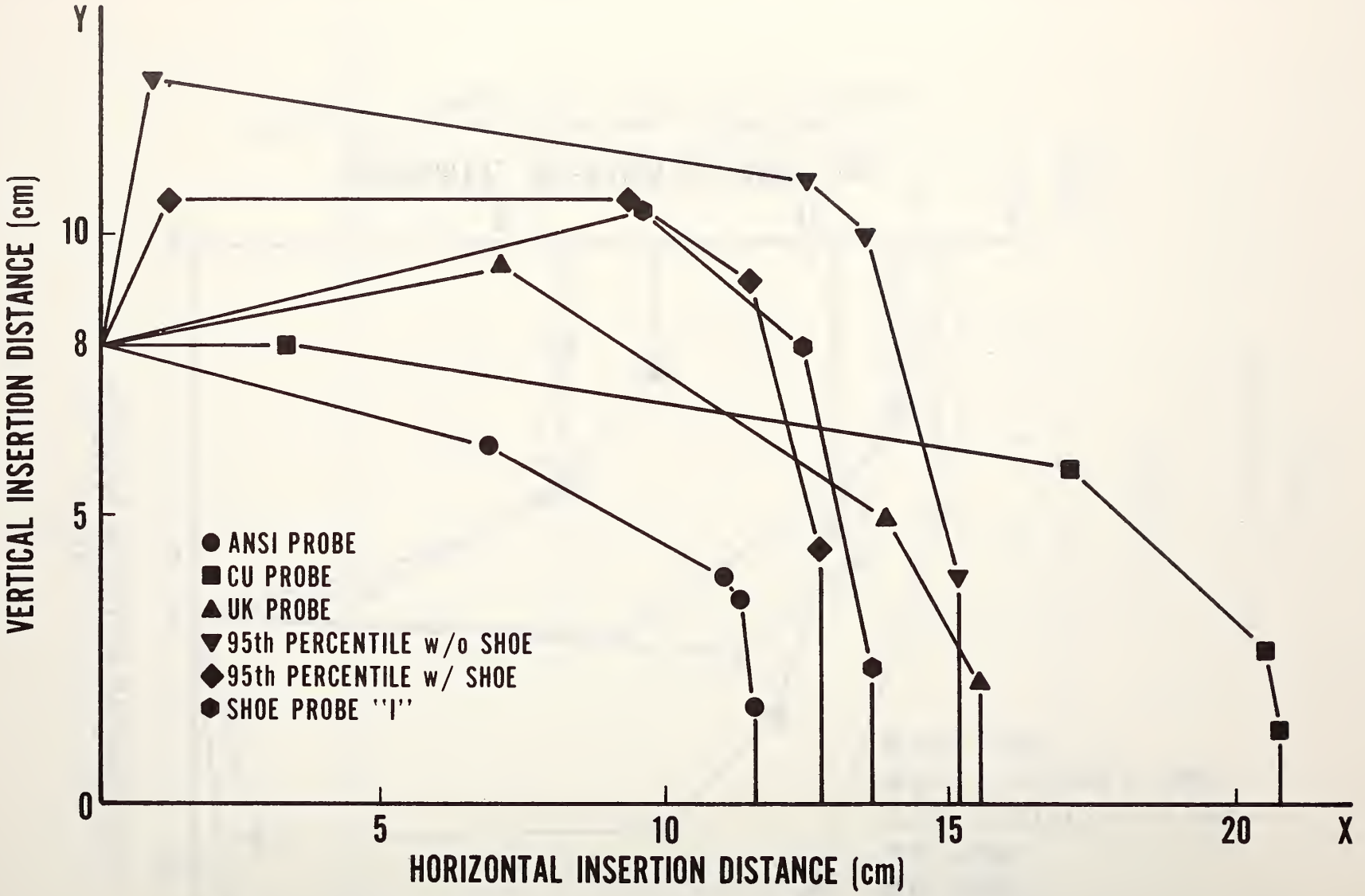

Figure 21. Safety Envelopes Shoe Probe I
Comparison - 8 cm Housing Height

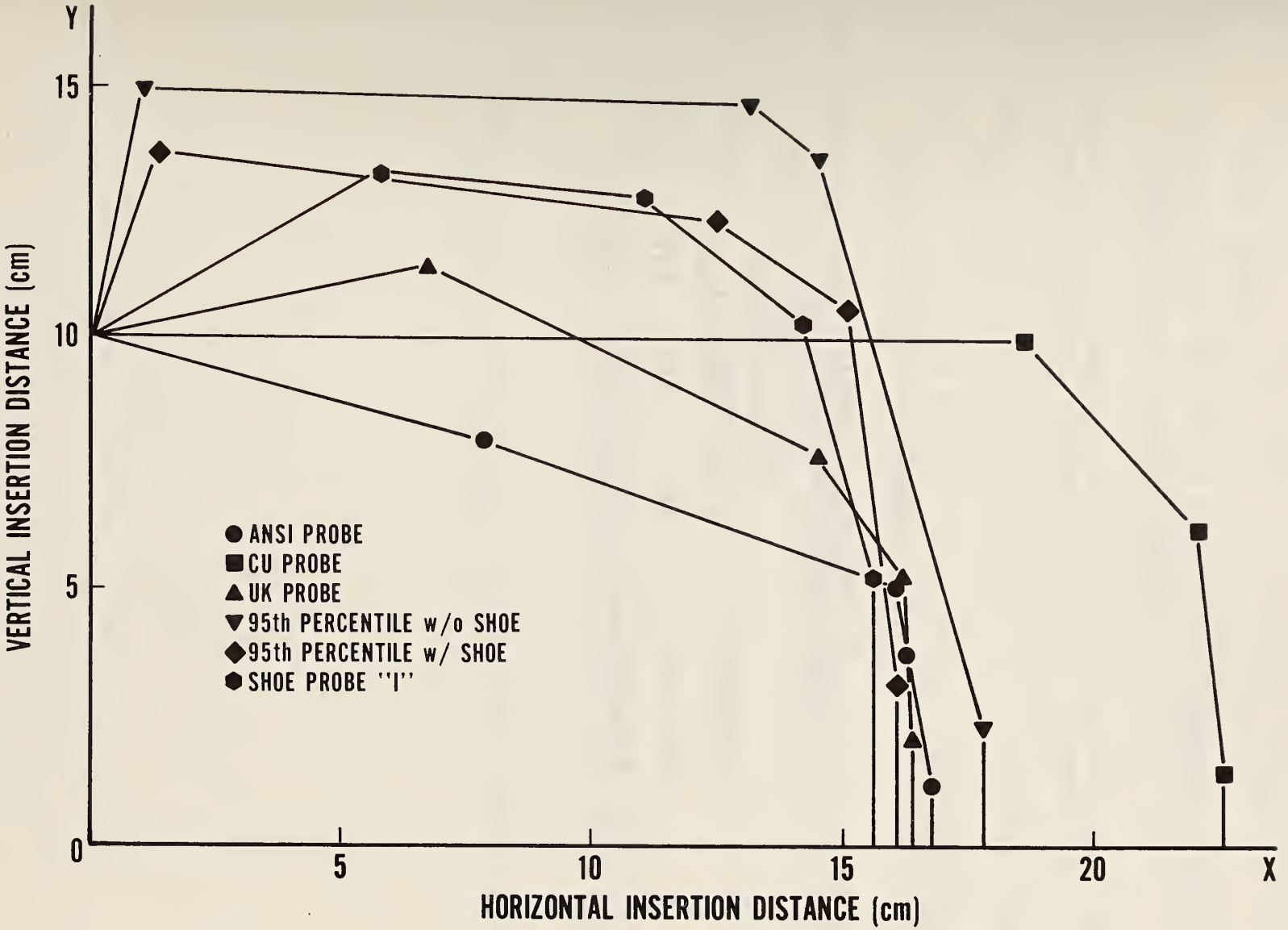

Figure 22. Safety Envelopes - Shoe Probe I Comparison - 10 cm Housing Height

Table 7

Percentage of Sample
Protected by Shoe Probe "I"

	Housing Height		
Condition	6 cm	8 cm	10 cm
With shoe	14%	14%	46%
Without shoe	1%	1%	4%

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APPENDIX A--UK Probe Design Rationale

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Dr J J Persensky
Human Factors Section
Product Systens Analysis Division
United States Department of Commerce
National Bureau of Standards
Washington, D.C. 20234

Your ref

Our tel ext/ref 375: AGE/20

Date 12 October 1976

Dear Sir

BS 5107: POWERED LAWNMOWERS

With reference to your letter of 9 September, we set out below comments from the Chairman of the Technical Committee responsible for BS 5107 on your enquiry regarding the development of the test probe shown in Fig 3 of the Standard:

"The foot probe referred to originated with the Technical Committees of B.S.I. dealing with lawnmowers and in fact I myself prepared the original drawing of it, based on initial criteria set by the committee. The committee first considered whether the object should simulate an adult foot, a child's foot, or should attempt a compromise between the two. While adult and child feet do present somewhat different problems, experiments with several different types of sample lawnmowers appeared to indicate that in practice, few machines which were acceptable when tested with an adult foot were unacceptable with a child's, whereas the reverse was not the case. When tested with a probe having an adult side view but a width in plan view designed to simulate a child's foot, some machines were found unacceptable which were, however, acceptable to both the adult and the child sized probes complete. On this basis, and bearing in mind that the operator of a mowing machine is more likely to be an adult male than any other class, the committee decided that this was the type of foot to be simulated.

In preparing the detailed design, I had informal consultations with members of the shoe manufacturing trade, to ascertain the size of shoe most commonly worn by adult males, and its approximate dimensions. There was of course a considerable variation in dimensions depending on styling etc., and I adopted some deliberate distortions to make the test as searching as possible while still reasonably realistic; such distortions include making the toe section untypically long and low, and the instep also low. A leg section was included, at an angle of 40° to simulate the limb being thrust well forward to give the maximum penetration of any guarding positioned at a fairly high level from the ground.

/see over

I would not pretend that this process was equivalent to a fine analysis of anthropometric data, but I do consider its use a sufficiently close approximation for the purposes intended.'

Yours faithfully

C H AGAR
Group Manager
Mechanical Department
CHA/SEW/FM

cc: ANSI

APPENDIX B--NBS Evaluation of Foot Probe

UNITED STATES DEPARTMENT OF COMMERCE
National Bureau of Standards
Washington, D.C. 20234

October 24, 1975

MEMORANDUM FOR John McGahan
Office of Consumer Product Safety

From: J. J. Persensky
Consumer Behavior and Information Section

Subject: Evaluation of Proposed Lawn Mower Safety Standard

Three of the tests proposed by CU were evaluated by this office: Test jj - Foot probe test, Test kk - Terrace test, and Test ll -Obstruction test. The tests relate to requirements 1205.18 and 1205.19 which discuss guards, shields, and grass catchers for rotary mowers. Tests kk and ll are specific to walk-behind rotary mowers, while Test jj relates to both walk-behind and ride-on mowers. Figures 4 (Foot Probe), 13 (Terrace Test), and 14 (Obstruction Test) describe the fixtures used in these tests.

The tests are considered separately below, but it must be remembered that Tests jj and kk utilize the same foot probe so that comments related to the probe are common to both tests.

Test jj - Foot probe test

1. The requirements associated with this test appear reasonable and adequate and are more stringent than earlier standards with regard to the blade contact hazard.

2. The test conditions are reasonable and are easy to achieve. However, a consistent method for measuring the lowest position of the blade should be stated in order to assure repeatability.

3. Section 1205.21 (jj) (2) (i) should be rewritten to clarify that the probe should be inserted slowly and pivoted in the vertical plane several times prior to maximum insertion. Also, it is not clear as to whether the 18 newton (4 lb.) force is to be measured at lateral insertion or when the probe is pivoted.

4. The materials and fixtures for the test are easily obtainable or constructed.

5. Two testers are necessary to adequately perform this test, i.e., one to insert and observe the probe and one to move the mower blade.

6. In order to evaluate this test it was necessary to validate the probe design. To accomplish this, several probes, in addition to the proposed probe were tested.

These were:
- A. CU adaptation of the UL probe (proposed by offeror),
- B. ANSI probe (currently used to determine compliance to ANSI B71.1-1972),
- C. United Kingdom probe (drawings Attachment A), and nine shoe probes constructed with shoes representing the population of lawn mower users. These were:
- D. Male, 95th percentile adult, wide, leather shoe,
- E. Male, 95th percentile adult, narrow, leather shoe,
- F. Male, 95th percentile adult, soft last shoe,
- G. Female, 95th percentile adult, wide, leather shoe,
- H. Female, 95th percentile adult, narrow, leather shoe,
- I. Female, 95th percentile adult, soft last shoe,
- J. 11 year old, 5th percentile, wide leather shoe,
- K. 11 year old, 5th percentile, narrow leather shoe,
- L. 11 year old, 5th percentile, soft last shoe.

Each of these probes was used to perform Test jj on 6 walk-behind mowers and 4 ride-on mowers. The results are presented in Attachment B. Analysis of the data (Attachment C) indicated that of three generic probes (A, B, and C) the United Kingdom probe was most valid when compared with the shoe probes. Also the CU proposed probe is more stringent than the ANSI probe. Based on the data the United Kingdom probe should be considered for inclusion in the final standard instead of the probe proposed by the offeror.

Test kk - Terrace test

1. The requirement associated with this test is intended to provide additional (with relation to 1205.18) blade contact protection for the operator at the rear of the mower. This is a new test not present in voluntary standards. It also provides a means to assure that a rear trailing shield will not be damaged

2. The test conditions appear reasonable and are easily achieved. The test fixture can be constructed readily, however, the overall length and width measurements should be stated. It should be noted that the fixture must support the weight of the mower and tester. Also, since the critical area is the curvature of the terrace a simplified and smaller fixture might be constructed so as to maintain the radius of curvature but without the long slope and terrace. Finally, there is question as to the appropriateness of the proposed radius of

curvature. There is no rationale stated for this value. The final value might be based on a survey of actual terrace faces using the smallest existing radius.

3. Procedurally, there is no statement of force for insertion of the probe. On the mowers tested there was a clear differentiation among mowers which met the criteria and those which did not (see data Attachment D). Some force is required to lift a trailing shield by inserting the probe. Those mowers which failed to meet the criteria had trailing shields which were constructed of material which was rigid enough to lift off of the surface of the fixture allowing blade contact. Other shields could not be raised without considerable insertion force. The test should state a maximum insertion force.

4. Comments regarding the foot probe are stated in the discussion of Test jj and apply to Test kk.

5. Two testers are necessary to perform this test.

Test ll - Obstruction test

1. Test ll is designed to prevent any loss of protection from guards or shields when the mower passes over an obstruction or over a depression in the mowing surface. Further, the intent is to reduce the probability that a rear trailing shield will be removed because of its nuisance value if the shield catches on obstructions.

2. The test conditions appear reasonable and easy to achieve. The test fixture can be easily constructed, however, overall length and width measurements should be stated. There is no rationale for the criteria values selected for the obstructions.

3. Procedurally a problem exists in that there is no statement as to forces or speeds for moving the mower over the obstructions. In the course of testing it was observed that with sufficient speed all mowers would fail to meet the criteria because the mower would bounce, but when pulled across the obstructions slowly only a few mowers failed the test. The data presented below was based on fast, slow, and medium speeds, where the medium speed was a little faster than walking. The data are from six walk-behind mowers.

Test 11

Number of mowers which fail or meet test criteria

Criteria	Depression	Obstruction
Fails	4	2
Meets	2	4

From this data it can be seen that most mowers do not meet the criteria for Test 11.

SUMMARY

Three major suggestions are presented in the above discussion for alternatives to tests jj, kk, and 11.

1. Test jj - The United Kingdom foot probe should be required by the safety standard rather than the proposed modification of the UL probe.

2. Test kk - A maximum force should be stated for insertion of the foot probe. The United Kingdom probe should be used.

3. Test 11 - A force or speed should be stated for movement of the mower over the obstructions.

cc: John Donaldson

Attachments: A - Drawing of United Kingdom probe
B - Data, Test jj
C - Analysis of data from Test jj
D - Data, Test kk

Attachment B
Data, Foot Probe Test

Data from foot probe insertion for six walk-behind mowers and four ride-ride-on mowers as per Test jj.

Probe	Walk-behind		Ride-on	
	Blade Contacts	No Blade Contacts	Blade Contacts	No Blade Contacts
A	3	3	4	0
B	0	6	0	4
C	5	1	4	0
D	4	2	4	0
E	5	1	4	0
F	5	1	4	0
G	3	3	2	2
H	5	1	4	0
I	5	1	4	0
J	5	1	3	1
K	4	2	4	0
L	6	0	4	0

Attachment C
Analysis of Data from Test jj

In order to determine the "best" generic probe (CU, ANSI, or United Kingdom) an attempt was made to compare those probes with shoe probes which were assumed to be representative of the population of lawn mower users, i.e., 95th percentile adult male to 5th percentile 11 year old. The analysis was performed using the following assumptions and data collected as per Test jj.

Assume:

1. The population of lawn mower users ranges from the 95th percentile adult male to the 5th percentile 11 year old.

2. The shoe probes tested are representative of that population.

3. The "ideal" probe would duplicate the entire population of shoe probes, both with regard to blade contact and misses.

Six walk-behind and four ride-on mowers were tested using the three generic probes and nine shoe probes. Data were accumulated on blade contact for each probe on each mower. The following table is based on the number of agreements between each generic probe and each shoe probe. That is, if a generic probe and a shoe probe both contacted the blade a point was scored, or if both failed to contact the blade a point was scored. If only one of the pair contacted the blade there was no agreement, i.e., no point scored. Each cell has a maximum value of six.

Table 1.

Number of agreements between each generic probe and each shoe probe for six walk-behind mowers.

Generic Probes

Foot Probes	A	B	C
D	5	2	5
E	4	1	6
F	4	1	6
G	4	3	4
H	4	1	6
I	4	1	6
J	4	1	6
K	5	2	5
L	3	0	5
Total Agreements	37	12	49

Assume further that the ideal probe would agree perfectly with all shoe probes for a Total Agreements of 6 x 9 or 54.

Now, to test the statistical significance of these data the standard error of proportion is appropriate for each pair assuming a population of 54.

First compute the proportion of each total agreements.

Probe A - .68
Probe B - .22
Probe C - .91

The significance of the proportions is computed by

$$z = \frac{P_1 - P_2}{\sqrt{\frac{P_1 (1 - P_1) + P_2 (1 - P_2)}{N_1 + N_2}}}$$

where P_1 = proportion of group 1
P_2 = proportion of group 2
N_1 = number of entries in group 1
N_2 = number of entries in group 2

So, for comparisons

AB $$z = \frac{.68 - .22}{\sqrt{\frac{.68 (1 - .68) + .22 (1 - .22)}{54 + 54}}}$$

$z = 7.66$ $p < .01$

AC $$z = \frac{.68 - .91}{\sqrt{\frac{.68 (1 - .68) + .91 (1 - .91)}{54 + 54}}}$$

$z = 4.37$ $p < .01$

BC $$z = \frac{.22 - .91}{\sqrt{\frac{.22 (1 - .22) + .91 (1 - .91)}{54 + 54}}}$$

$z = 14.24$ $p < .01$

Therefore, all probes are significantly different from each other. Further, the absolute values indicate that the United Kingdom probe is most similar to the shoe probes.

When performing these calculations for the four ride-on mowers it was determined that probes A and C were equivalent and probe B was significantly different. See data in Table 2.

Table 2

Total agreements between each generic probe and all shoes probes.

	Probe		
	A	B	C
Total Agreements	33	3	33
Proportion	.92	.08	.92

Attachment D
Data, Terrace Test

Data from foot probe insertion in six walk-behind mowers as per Test kk.

Probe	Blade Contact	No Blade Contact
A	2	4
B	2	4
C	2	4
D	2	4
E	2	4
F	2	4
G	2	4
H	2	4
I	2	4
J	2	4
K	1	5
L	2	4

APPENDIX C

Foot Length Data

Presented below are foot length data presented in various Human Factors Handbooks and the data from the present study.

Source			Percentile 5th	95th
Van Cott and Kinkade (5)				
	Adult	Male	23.9	29.5
		Female	22.1	26.2
Military Standard 1472-B (6)				
	Adult	Male	24.4	29.0
		Female	22.2	26.0
McCormick (7)				
	Adult	Male	24.8	28.6
		Female	22.7	26.1
University of Michigan (8)				
	11 years old	Male	19.7	23.3
		Female	19.0	23.0
Present Study				
	11-65 years old	Male	23.1	29.3
		Range	19.3	30.5
		Female	21.4	25.4
		Range	19.8	26.2

APPENDIX D--Research Consent Form

NBS-783
12-75

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

3. Cost Control No.

RESEARCH PARTICIPANT AGREEMENT

1. Principal Investigator
Dr. J. J. Persensky

2. Division/Section
441.02

4. Location
XX Gaithersburg
X Other (specify)
Local school

5. Experiment Name/Code
Foot Simulator Evaluation (Probes)

6. Description of Experiment:
The purpose of this research is to determine how far a foot can be pushed under an opening and then tilted upward. It is being done so that protective shielding for consumer products (such as lawn mowers) can be evaluated. The equipment will be a box-like rig and a camera. The participant will place his/her foot through the opening in the box and turn the foot upwards. While the foot is in the box photographs will be taken.

7. Risks to Participant:
No accidents are expected.

8. Responsibilities of Participant:
The participant, with informed consent, will follow instructions, answer questions about age and sex, and allow the investigator to weigh them and measure their height and feet.

9. Responsibilities of Investigator(s):
The investigator will (1) fully explain the test procedure, (2) explain the purpose of the test, (3) ensure safe test conditions, and (4) keep personal information confidential.

10. IT IS UNDERSTOOD THAT EITHER THE PRINCIPAL INVESTIGATOR, THE PARTICIPANT, OR THE PARTICIPANT'S PARENT OR GUARDIAN MAY TERMINATE THE PARTICIPANT'S INVOLVEMENT IN THE RESEARCH AT ANY TIME WITHOUT INCURRING LEGAL LIABILITY FOR SUCH TERMINATION.

11. I hereby certify that my participation is voluntary and that I have read and accept the terms of this agreement.

Participant, or Parent or Guardian (Signature)	Date
12. Principal Investigator (Signature)	Date
13. Early Termination by (Signature)	Date

NBS-114A (REV. 7-73)

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14. Sponsoring Agency Code

15. SUPPLEMENTARY NOTES

16. ABSTRACT (*A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.*)

This document is the final report for the Consumer Product Safety Commission of an evaluation of the adequacy of existing generic foot probes. The Human Factors Section at NBS compared the dynamic characteristics of three generic probes with those of potential lawn mower users' feet.

Horizontal and vertical insertion distances for the generic probes and the foot data were used to develop safety envelopes for various simulated housing heights. Inspection of the safety envelopes at 6, 8, and 10 cm housing heights indicates that of the three generic probes, the UK probe most closely approximates the foot data. Only the UK probe passes through the area above the plane of the housing opening.

However, a comparison of each individual's data (rather than aggregate data) was made with each generic probe to determine the percentage of participants who would be completely protected by each generic probe. These data indicate that at least one point of each individual's foot movement data would fall outside of the safe area defined by the generic probe envelopes. Therefore, a lawn mower meeting the criteria of any of the generic foot probes would not completely protect any of the participants in the study.

Recommendations for a modification of the UK probe and for further research are discussed.

64341

17. KEY WORDS (*six to twelve entries; alphabetical order, capitalize only the first letter of the first key word unless a proper name; separated by semicolons*)

Consumer products; generic probes; human factors; lawn mowers; safety; standards

18. AVAILABILITY

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